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Sacramento River
Mercury Control Planning Project

Final Project Report

Prepared for

**Sacramento Regional
County Sanitation District
(SRCSD)**

MARCH 1997

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Transmittal: March 31, 1997

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Final Report for the Sacramento River Mercury Control Planning Project

Enclosed please find one copy of the Final Report for the Sacramento River Mercury Control Planning Project.

It has been a pleasure working with you. Thank you all again for your interest and participation in the project, and for all your insightful and constructive comments. The project could not have been completed without your help and has been greatly enhanced by your input.

If you have any questions or comments, please call.

LARRY
WALKER

ASSOCIATES

Sacramento River
Mercury Control Planning Project

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ABSTRACT

This document presents the work performed under the Sacramento River Mercury Control Planning Project. The objective of this project is to develop a proposed implementation plan for control of mercury from point and nonpoint sources within the Sacramento River watershed. The work for the project was performed in two phases. The first phase of the project consisted of a year-long monitoring program within the Sacramento River watershed, comprising both water quality and biota monitoring efforts. In the second phase, the monitoring results were used to evaluate and identify significant point and nonpoint sources of mercury, to estimate mass loads from these sources, and to evaluate prospective mercury control strategies. The methods and results of these efforts are described herein, and a preliminary implementation plan for a cost-effective mercury source control strategy is proposed.

ACKNOWLEDGMENTS

This project could not have been completed without the help of the following institutions and individuals:

California State Water Resources Control Board
Greg Frantz (Project Contract Manager)
Rick Humphreys

Central Valley Regional Water Quality Control Board
Bill Croyle

Sacramento Regional County Sanitation District
Rosemary Clark (District Project Manager)

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We are especially grateful to Malcolm McEwen doing the hard work to initiate this project. We also extend our appreciation to all the interested individuals who took the time to attend the public meetings and to provide their insight and comments.

This project was made possible by funding provided by the County of Sacramento and by the U.S Environmental Protection Agency under a 205(j) matching funds grant.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

MERCURY SOURCES IN THE SACRAMENTO RIVER WATERSHED

Mercury has been used on a global scale in many industrial, agricultural, and domestic applications. Although many uses of mercury are now prohibited or severely restricted, mercury's biocidal properties have been incorporated into seed coatings, pharmaceuticals, paints, swimming pool treatments, and a variety of other products. Mercury is still widely used in the manufacture of electrical equipment, including switches and fluorescent and mercury vapor lighting fixtures. The primary causes of much mercury pollution of surface waters world-wide have been chlor-alkali plants, vinyl chloride and acetaldehyde manufacture, and paper and pulp mills (CVRWQCB 1987). Drainage from mercury, gold, and base metal mines, and the use of mercury for amalgamation of gold and silver have been responsible for extremely high levels of mercury pollution in some waterways. Recent research has also identified atmospheric transport and deposition of mercury from fossil fuel combustion and incineration of industrial and municipal wastes as significant processes contributing to local, regional, and global mercury pollution (Chu and Porcella 1995; Balogh and Liang 1995).

While the Sacramento River watershed has been (and continues to be) impacted by many of the sources and processes cited above, two unique factors have had a dominating influence on mercury contamination of surface waters in the Sacramento River watershed: (1) the western side of the watershed contains extensive natural mercury deposits and (2) the eastern side of the watershed was discovered to be a profitable gold mining region. The Coastal Range on the west side of the Sacramento Valley is rich in natural mercury deposits, and mercury mines in this region are the source of the majority of the mercury mined in the United States (CVRWQCB 1987). Most of the mercury mines (including the Sulfur Banks Superfund site near Clear Lake) are in the Cache Creek and Lake Berryessa drainages which ultimately join the Sacramento River below the Sacramento metropolitan area. In addition to the many active and inactive mercury mines, there are unmined mercuric sulfide (cinnabar) deposits throughout the Coastal Range. Drainage from mine tailings and natural mercury deposits have been determined to be responsible for locally high mercury concentrations in water and fish (*ibid.*) and may contribute substantially to Sacramento River mercury loads.

Much of the mercury mined on the east side of the Sacramento valley was transported for use in historic gold mining operations in the Sierra Nevada foothills. It has been estimated that millions of kilograms of quicksilver (elemental mercury) were carried into the Sierra Nevada for the purpose of extracting and processing gold from this region. Most of this mercury was discharged into tributaries of the Sacramento and San Joaquin Rivers with the mine tailings from hydraulic and river mining operations. The most active gold mining region in the Sierra Nevada was centered (approximately) around Nevada City. Gold mines and mine tailings in this region have been shown to be significant sources of mercury (CVRWQCB 1987).

PURPOSE AND SCOPE OF STUDY

The Sacramento River, from Lake Shasta to the Delta, is ranked among the top five rivers in the State of California in terms of resource value. Among those five rivers, it has also been ranked highest in terms of its impaired condition. These impairments are associated with elevated concentrations of trace elements (copper, cadmium, zinc, and mercury), elevated levels of dioxin, problems associated with flow and temperature regimes, toxicity, and pesticides and herbicides (CSWRCB 1992a).

Although mercury is only one of several pollutants responsible for Sacramento River impairments, potential health and regulatory concerns associated specifically with mercury are widespread in the watershed. In 1986, the Central Valley Regional Water Quality Control Board (CVRWQCB) conducted a survey of mercury contamination of sediment and fish throughout the Sacramento River watershed. Mercury was detected in elevated levels in sediment in the Yuba and Bear Rivers, Cache Creek, Putah Creek, and Stony Creek. Mercury levels in fish captured in water bodies in certain tributaries of the Sacramento River exceeded the 1973 National Academy of Sciences guideline to protect aquatic resources and their predators (0.50 ppm) (CVRWQCB 1987). These mercury bioaccumulation problems were observed in portions of the coast range where mercury is naturally occurring, in the Sierra Nevada Range where mercury was used (and is still used) to process gold, and in the Delta. More recently, the CVRWQCB has determined that mercury is responsible for impairment of the aquatic habitat beneficial use in the Sacramento River between the Colusa Basin Drain and the Sacramento-San Joaquin Delta (CSWRCB 1992a). The California Department of Health Services has issued a consumer advisory limiting human intake of fish in the Sacramento-San Joaquin Delta (*ibid.*). Mercury in the Sacramento River is also concern to the Sacramento Regional County Sanitation District (SRCSD), the operator of the Sacramento Regional Wastewater Treatment Plant (SRWTP), because of the potential difficulty in meeting future effluent limitations for mercury.

A recent study of ambient trace element concentrations at Freeport, just upstream of the discharge point for the SRWTP, has demonstrated that mercury will be among the most difficult pollution problems to solve in the Sacramento River (LWA 1992). Although mercury has been identified as a cause of significant beneficial use impairment of the Sacramento River from Colusa Basin Drain to the Delta, insufficient information has been available to adequately locate and characterize significant point and nonpoint sources. Previous watershed-wide mercury assessments have been based primarily on sediment and fish tissue data, and to a lesser extent on water column data (CVRWQCB 1987). Although these assessments have provided important information regarding the general location of mercury sources within the watershed, they have been unable to pinpoint significant sources or provide useful estimates of mass loads. For example, while mine tailings are known sources of mercury, the relative contribution to total loads in the Sacramento River from this source is not known (Montoya, et al. 1988) and has not been estimated using results of ambient water column monitoring.

The objective of the Sacramento River Mercury Control Planning Project is to develop a proposed implementation plan for control of mercury from identified point and nonpoint sources within the Sacramento River watershed. Development of the proposed implementation plan is supported by several key study elements: (1) a year-long mercury monitoring program implemented within the Sacramento River watershed; (2) estimates of mass loading from key tributaries of the Sacramento River; (3) evaluation of the distribution of mercury sources and identification of potential mercury loading "hot spots"; (4) evaluation of the effect of major reservoirs on mercury loading; and (5) evaluation of appropriate mercury control strategies for the watershed. Because of the apparent importance of the historic Sierra Nevada gold mining region as a significant source of mercury to the Sacramento River (CVRWQCB 1987; CSWRCB 1992b), this study focused on the Feather River, Yuba River, and Bear River drainages of the Sacramento River watershed.

STUDY APPROACH AND TECHNIQUES

The initial phase of this study was an year-long water quality and biota monitoring program focusing on areas previously identified as problem areas for mercury loading and bioaccumulation. The water quality monitoring program was designed to characterize water quality and loading from major Sacramento River tributaries during critical hydrographic periods and events, including dry season low flows, early season storm flows, annual peak flows, and spring snow melt flows. The biota monitoring program was designed to characterize the distribution of mercury sources and to provide an integrated assessment of longer-term mercury bioaccumulation in biota in the study area. Sampling and analytical methods used for water quality and biota were selected to reliably detect mercury at levels below expected ambient concentrations.

The results of the monitoring program were used to evaluate and identify significant point and nonpoint sources of mercury, to estimate mass loads from these sources, and to evaluate prospective control strategies. These evaluations were used to select and propose the most appropriate mercury control strategy and to develop a preliminary implementation plan for the proposed control strategy. The purpose of this document is to present the results and recommendations of the study described above. The approach and methods used in this study will be evaluated for use in future mercury control studies in the Sacramento River watershed.

DATA COLLECTION AND INTERPRETATION

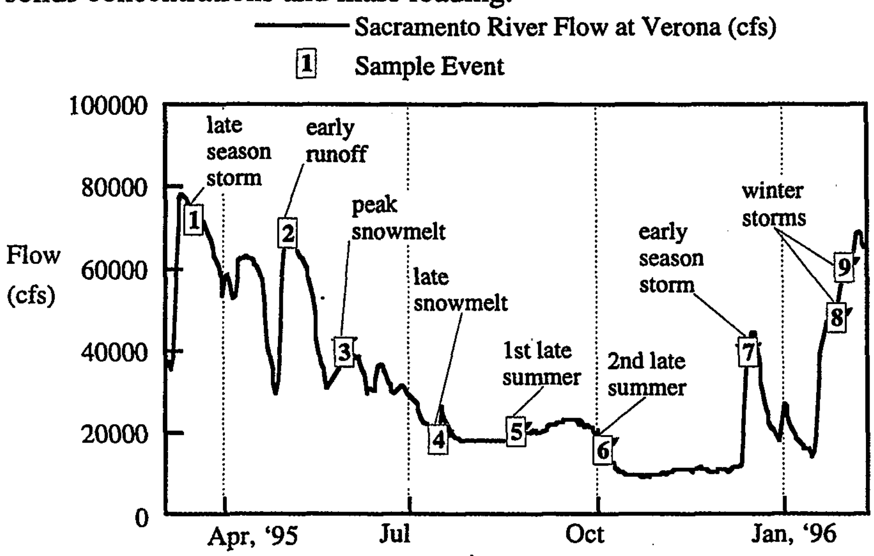
The first phase of the Sacramento River Mercury Control Planning Project was designed to identify sources of mercury loading using a combination of water quality and biota data collected from tributaries to the Sacramento River. The methods, results, and interpretation of the water quality and biota sampling facets of the Sacramento River Mercury Control Planning Project are presented below.

METHODS

The data collection element of this study consisted of (1) water quality sampling to estimate mercury mass transport in the Sacramento River watershed, and (2) biota sampling to identify localized areas of elevated bioavailable mercury in selected sub-basins. This approach was developed based on comments and input from the Project Technical Advisory Committee (TAC). Water quality and biota samples were collected and analyzed using the methods described in the Quality Assurance Project Plans (LWA 1995; Slotton 1995; attached). These methods are summarized below.

Water Quality

Water column samples were collected from seven locations (Figure 1). Four sampling sites were selected for the purpose of characterizing the relative mass loads of mercury and total suspended solids (TSS) from the Feather River watershed, the Yuba River watershed, and the Sacramento River upstream from the confluence with the Feather River. Three additional sites were selected around Englebright Reservoir (on the Yuba River) to assess the effect of the reservoir on mercury, methylmercury, and suspended solids concentrations and mass loading.



Mercury Project Sample Events and Sacramento River Flows at Verona

Water column samples were collected for a total of nine sampling events. Samples were collected during a range of flow conditions representative of the main hydrological regimes for the watersheds sampled for the period from

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C-035496

March, 1995 to February, 1996. The flow conditions sampled were generally characterized as (1) early wet season storms, (2) dry season low flows, and (3) late spring snowmelt runoff.

Water column samples were collected using so-called "clean" or "ultra-clean" methods to minimize contamination. Samples consisted of cross-sectional composites and near-shore grabs collected using a peristaltic pump system and specially cleaned tubing. Water quality samples were analyzed by EPA method 1630 for mercury and methylmercury by Frontier Geosciences (Seattle, WA). Analyses for TSS by EPA method 160.2 were performed by Anlab (Sacramento, CA). Temperature, dissolved oxygen, pH, and conductivity measurements were conducted in the field by the sampling crew.

Biota

Biota samples were collected from 21 locations in the watersheds of the Feather River, the Yuba River, and the Bear River for this study. Sampling locations were selected to augment previously collected data within these watersheds and from the American River watershed. Biota data from a total of 55 sampling locations were evaluated to identify bioavailable mercury "hot spots" within eastern tributaries to the Sacramento River. At the three sites around Englebright Reservoir on the Yuba River, biota were collected for five sampling events to assess seasonal variability and the effects of reservoirs on mercury bioavailability. Other sites were sampled for single sample events. Figure 2 illustrates the locations of all biota sampling sites represented by data considered in this study.

Invertebrate samples consisted of composites of 1 to 50 individuals per species of a similar size. Invertebrates were collected with a stainless steel kick screen from riffle habitats, and sorted with Teflon™-coated forceps into acid-cleaned 30 mL glass jars with Teflon™-lined caps. Individual fish were collected by angling. Fish muscle samples were taken from fresh-caught fish at streamside with a stainless steel scalpel and placed into acid-cleaned digestion tubes with Teflon™-lined caps. Biota samples were analyzed for total mercury by a modified Cold Vapor Atomic Adsorption (CVAA) method. Selected sub-samples of biota tissue composites were also analyzed by EPA method 1630 for methylmercury by Frontier Geosciences.

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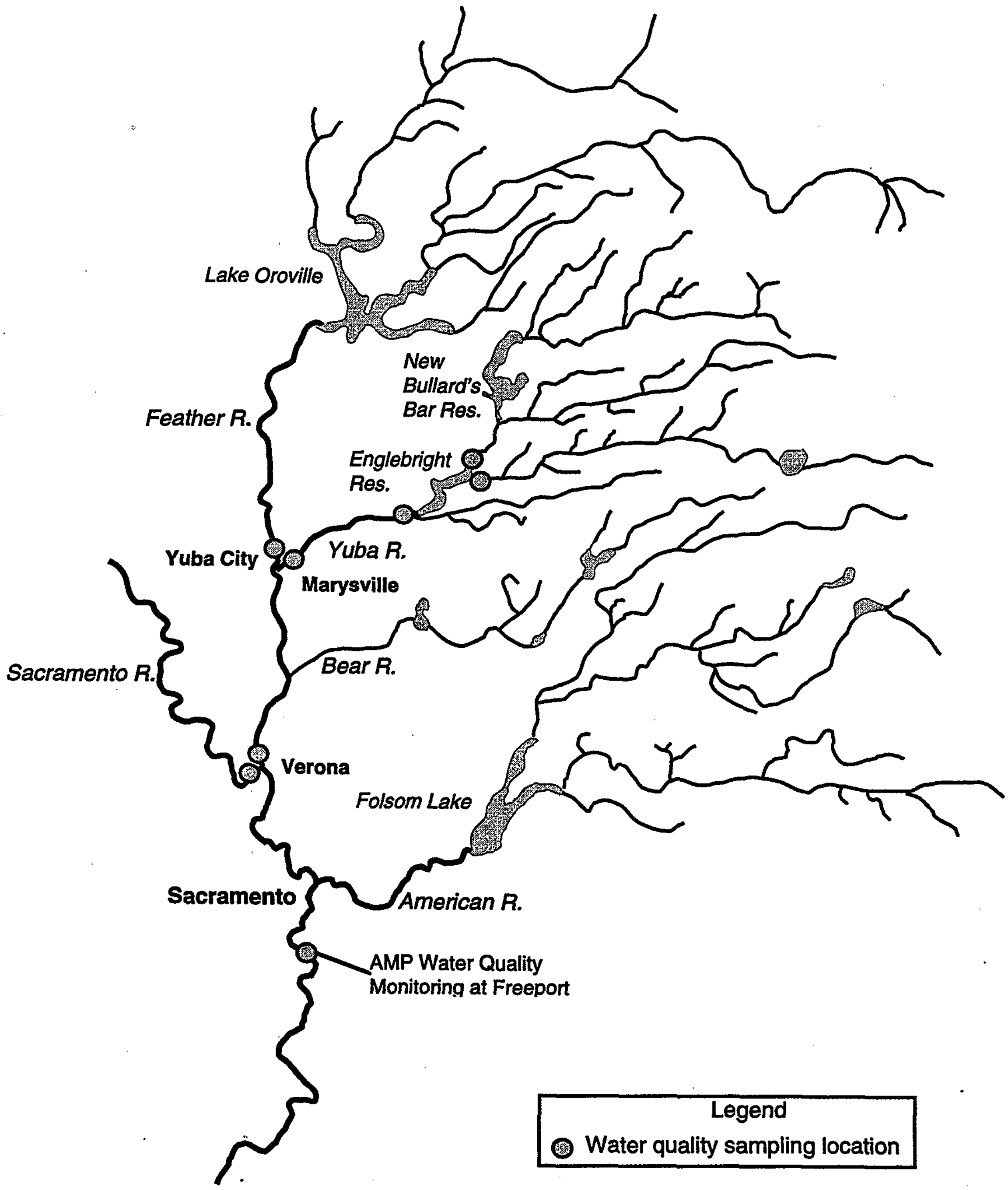


Figure 1. Mercury Project Water Column Sampling Sites

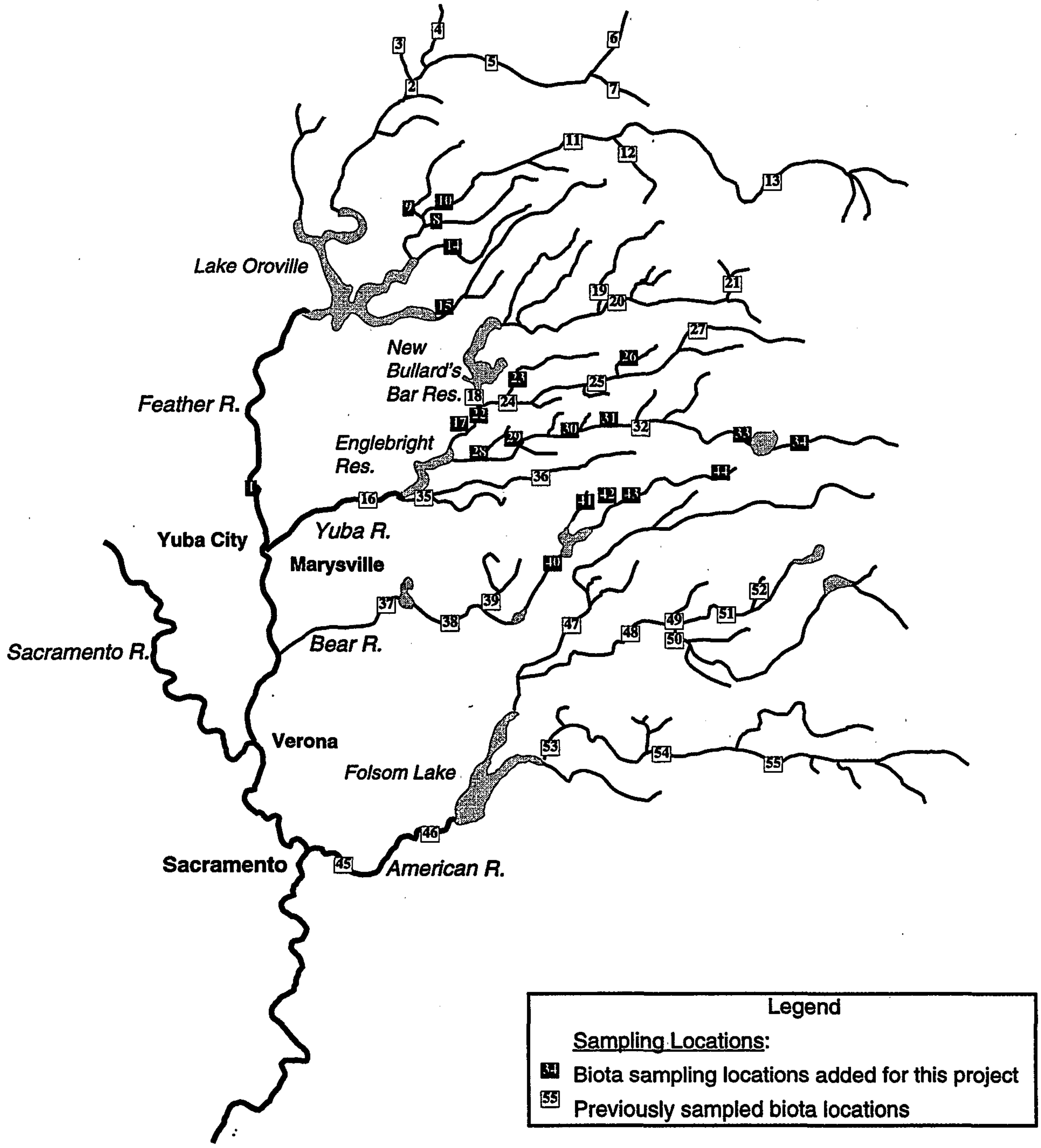


Figure 2. Mercury Project Biota Sampling Sites

RESULTS

Water Quality Data

Water quality data are summarized in tables and illustrated as time series plots in Appendix A.

Water quality data and mean daily flows measured by USGS during each sampling event were used to calculate mercury loads (kilograms of mercury per day) for each event.

USGS Gaging Stations Used in Mass Loading Calculations

Stream or Reach	USGS Gaging Station and Number	
Sacramento River at Freeport	Sacramento River at Freeport	11447650
American River	American River at Fair Oaks	11446500
Sacramento River at Verona	Sacramento River at Verona	11425500
Feather River at Yuba City	Feather River at Gridley	11407150
Yuba River at Marysville	Yuba River at Marysville	11421000
Englebright Reservoir outflow	Yuba River near Smartville	11418000
Deer Creek	Deer Creek near Smartville	11418500
South Fork Yuba River	South Fork Yuba River at Jones Bar	11417500
Middle and North Forks Yuba River	New Colgate Powerplant near French Corral	11413510
	N. Yuba River below Bullards Bar Dam	11413520
	Middle Yuba River below Our House Dam	11408880
	Oregon Creek below Log Cabin	11409400
Bear River	Bear River near Wheatland	11424000
Cache Creek	Cache Creek at Yolo, CA	11452500
Yolo Bypass	Yolo Bypass near Woodland	11453000

Event mass loads for each location were calculated by multiplying mean daily flows and total mercury concentration for each sampling event.

Average annual loads of mercury were also estimated for tributaries and selected reaches of the Sacramento River using historical flow data from U.S. Geological Survey for the period 1946 through 1995 (USGS 1996). Average annual loads were estimated by the following method:

(1) relationships between water quality data and mean daily flows were estimated for each site using Analysis of Covariance (ANCOVA) regression analysis;

(2) the results of the regression analysis were used to estimate mercury concentrations corresponding to historical monthly average flows (monthly flows were used instead of an annual average flow to capture the seasonal variability in flows);

(3) average loads were calculated for each month (mercury concentration times monthly average flow times number of days per month); and

(4) monthly loads were summed to provide annual average loads.

Average annual loads from the Sacramento Regional Wastewater Treatment Plant (SRWTP) were calculated using actual daily flow data and average annual concentrations of mercury in dechlorinated final effluent.

In addition, relative loads were estimated for selected reaches and the SRWTP as a percentage of the annual and WY 1995 Sacramento River load at Freeport. Average annual Sacramento River loads at Freeport were calculated using water quality data from the Ambient Program of the Sacramento River Coordinated Monitoring Program (LWA 1996) and historical flow data. Relative mercury loads were calculated as a percentage of the average annual loads for the Sacramento River at Freeport.

Estimates of loads were also modeled for USGS Water Year 1995 (October 1994 through September 1995), the most recent year with complete flow data sets for all the sites used in this study. Loads for Water Year 1995 were calculated using the same load-flow regression relationships as part of a continuous simulation model driven by Water Year 1995 daily flow data. Monte-Carlo simulation methods were used to characterize the variability and confidence limits of the estimates of annual loads for Water Year 1995. These results are also used to provide an estimate of the reliability for average annual load estimates.

Mass Loading

Estimated average annual and Water Year 1995 (defined as October 1994 through September 1995 by USGS) mercury loads are illustrated in Figure 3. Relative mercury loads contributed by specific sub-drainages to the Sacramento River are illustrated in Figure 4. Estimated average annual loads are also presented in Figure 5. Average annual loads and relative rank, relative loads, and relative flows are also summarized in Table 1a for selected sub-drainages and the Sacramento Regional Wastewater Treatment Plant (SRWTP). Water Year 1995 loads and relative rank, relative loads, and relative flows are also summarized in Table 1b. Confidence intervals are provided for estimates of total mass loads and relative mass loads for Water Year 1995. (Note: it is not possible to calculate similar confidence intervals for the annual average load estimates.)

Sacramento River above Verona

An important result from the water quality portion of this study is that in an average year, the Sacramento River above the confluence with the Feather River at Verona appears to contribute approximately 61% of the total annual mercury load measured in the Sacramento River at Freeport, while contributing only 52% of the flow. In high water years such as Water Year 1995, the proportion of the estimated load contributed by the

Sacramento River above Verona was similar (58%). The primary reason for the apparent minor decrease in the percentage of loading in Water Year 1995 is that approximately 40% of Sacramento River total annual flows and mercury loads above Verona were diverted to the Yolo Bypass at the Fremont Weir. Although flows in the Yolo Bypass do not contribute to the mercury load measured at Freeport, these mercury loads eventually re-enter the Sacramento River below Freeport through Cache Slough (just upstream from Rio Vista) and contribute to the total mercury loads to the Delta and the San Francisco Bay estuary.

The relatively high proportion of mercury loads contributed by the Sacramento River above Verona was an unexpected result. Although there are a number of inactive mercury mines in the coastal range on the west side of the Sacramento Valley (including the Sulfur Banks Superfund site near Clear Lake), the streams that drain this mining region (Cache Creek and Putah Creek) flow into the Yolo Bypass and do not contribute to loads measured at Verona or Freeport. However, there are a number of other possible sources of mercury to this part of the Sacramento River watershed, including:

(1) Several former gold mining areas:

- the Cherokee Mine area, which is drained by Butte Creek to the Sacramento River (through Butte Sink)
- gold mining activity on Butte Creek South of Chico
- gold mining activity in Shasta County.

(2) The Iron Mountain Mine and other massive sulfide mineral deposits in Shasta County;

(3) Natural deposits of marine shales on the west side of the Sacramento Valley;

(4) Agricultural runoff containing mercury remaining from historical use of fungicidal mercury compounds.

At this time, there is insufficient information to evaluate the relative importance of these potential mercury sources. However, studies currently being conducted by the U.S. Geological Survey (USGS NAWQA and USGS/Sacramento County Metals Transport Study) may provide important new information on mercury sources and transport in the Sacramento River watershed.

Yuba River Watershed

The South Fork of the Yuba River drains one of the most active gold mining regions in the Sierra and was observed to have the highest total mercury concentrations compared to other monitored streams in the Feather River watershed. However, average annual mercury loads to the Sacramento River from the South Fork of the Yuba River were estimated to be less than 2% of the total annual load in the Sacramento River at Freeport. The combined flows of the Middle and North Forks of the Yuba River accounted for approximately 8% of the total flows in the Sacramento River at Freeport, but were estimated to be responsible for less than 2% of the average annual mercury loads. In total, the Yuba River watershed is estimated to contribute approximately 10% of the total flows and only 4% of the average annual Sacramento River mercury loads measured at Freeport. In Water Year 1995, the percent of the mercury load contributed by the Yuba River watershed increased to approximately 6%.

Feather River

The average annual mercury load contributed by the Feather River above Yuba City was low when compared to the flow contributed by the entire Feather River watershed. The Feather River above Yuba City contributed approximately 20% of the flow and only 12% of the average annual mercury loads estimated for Freeport. In Water Year 1995, the proportion of the mercury load contributed by the Feather River increased to approximately 18%.

Below the confluences with the Yuba River and Bear River, the mercury mass load for the Feather River watershed constituted approximately 25% of the average annual mercury loads estimated for Freeport. In Water Year 1995, the proportion of the mercury load increased to approximately 31%. Annual mass loads estimated for this reach suggest that an annual average of 9.8% of the total estimated Sacramento River mass load at Freeport enters the Feather River between Yuba City and the confluence with the Sacramento River at Verona. In Water Year 1995, the annual load to this reach was estimated to be 6.4%.

There are a number of potential sources of additional mercury loads for this reach of the Feather River. The only major stream entering the Feather River below Yuba City is the Bear River. This stream drains one of the most active Sierra gold mining regions and contributes approximately 2% of the total annual Sacramento River flow at Freeport. The Bear River (and its tributary, Dry Creek) also drain areas of massive sulfide mineral deposits, including the Spenceville base metal-sulfide mine and deposits inundated by Camp Far West Reservoir. The zinc sulfide-sphalerite associated with these deposits may have significant natural mercury levels (Churchill 1997). The biota data for this stream (discussed in following sections) also indicate that levels of bioavailable mercury are higher in the Bear River than in any of the other drainages monitored. While the biota data can't be used to directly estimate total mercury concentrations or mass loads, they strongly suggest that the Bear River contributes a substantial percentage of the total mercury load in the Feather River drainage.

Sacramento Regional Wastewater Treatment Plant (SRWTP)

The effluent flow from the SRWTP (located just below Freeport on the Sacramento River) is equivalent to approximately 1.1% of the flow and 4.8% of the average annual mercury loads estimated at Freeport. In Water Year 1995, the estimated proportion of the mercury load from the SRWTP decreased to approximately 2.2%, due to the overall increase in Sacramento River flows and mercury loads observed at Freeport.

Uncertainty and Mass Load Estimates

Estimates of mass loads and relative loading are necessarily associated with a degree of uncertainty. There are a number of factors that may contribute to errors in mass loading estimates including loading estimate assumptions, flow data error, annual and seasonal variability, sampling and analytical error, and uncharacterized loading sources. The effect of these factors on load estimates are discussed below.

Assumptions

The principle assumptions used in calculating load estimates are the following:

- Total mercury mass loads can be reasonably estimated as a function of stream flows (discharge) and total mercury concentration,
- there is a definable mathematical relationship between stream flows and mercury mass loads, and
- flows and loads for major stream reaches balance with flows for reaches downstream.

The main liability of the first assumption is that loading estimates are based solely on water column transport and do not account for bedload transport of mercury. At the present time, available information is inadequate to fully address the potential contribution of bedload transport to Sacramento River mercury loads. While the impact of bedload transport on Sacramento River mercury loads can not be dismissed on a strictly quantitative basis, consideration of some general characteristics of bedload transport processes provides some insight into its relative importance to total mercury loading.

Bedload transport is the movement of the bedded materials of the stream bottom. The Sacramento River, which is a low gradient system in the Sacramento Valley, has a bedload that is primarily sand (Dinehart 1997). In higher gradient streams or reaches, the bedload may include larger gravels and cobble material. The materials that make up the bedload differ from the relatively fine particulate matter suspended in the water column in some important ways. Sand and larger particles have less surface area per unit weight than the fine particles that make up the suspended sediments, and very little organic content. This results in a relatively low binding capacity for metals, so that the materials comprising the bedload are likely to have a relatively low concentration of mercury compared to suspended sediments. A second characteristic particularly relevant to mass loading is that movement of bedload materials is relatively slow compared to water column transport—on the order of meters per day for bedded materials versus fractional meters per second for suspended sediments (*ibid.*). Another phenomenon associated with the movement of bedded sediments has some potential for affecting mercury loading. Scouring of the downstream faces of bedforms during high flows (e.g. during the winters of 1995 and 1997) exposes older bed material and potentially may expose long-buried mercury deposits to be resuspended and transported downstream in the water column. However, resuspended older sediments with high mercury concentrations would be measured as part of the water column mercury load and are therefore incorporated into the mercury loading estimates for this study.

While the transport of mercury as part of the Sacramento River bedload unquestionably contributes to the overall mercury load delivered to Freeport, the combination of the characteristics of bedload materials and transport dynamics suggests that bedload transport comprises only a small fraction of the Sacramento River total sediment load and an even smaller fraction of the total mercury load. Based on this rationale, it can be assumed that although total mercury mass loading may be somewhat underestimated by focusing solely on water column transport, the overall conclusions regarding the relative importance of the sources of mercury loads will still be valid.

The assumption of a definable mathematical relationship between stream flows and mercury loads was validated by the regression analysis. This analysis found that the relationship between stream flows and loads, and between stream flows and mercury concentrations, was highly significant ($p<.0001$), indicating that modeling of mercury loads directly from load data was reasonable.

To assure that the assumption of flow balance was not violated, total Water Year 1995 flows at major stream confluences (the Yuba and Feather rivers at Marysville/Yuba City, the Sacramento and Feather rivers at Verona, and the American and Sacramento rivers at Sacramento) were balanced with downstream flows. Because average annual loads are based on average flow statistics instead of synoptic flow data, the assumption of flow balance could not be strictly enforced. However, average annual flows upstream from major confluences balanced to within 1% with downstream flows, indicating that this assumption was also reasonable for average annual flow data.

Flow Data Error

Because mass loading is largely dependent on stream flow, any errors or bias in the flow data used for estimates could have a substantial impact on the load estimates. A systematic bias in the flow data for any river reach would result in a similar bias in the load estimates for that reach. However, based on flow balance calculations, USGS flow data sets do not appear to be systematically biased, and therefore there is no basis to modify load estimates for this type of bias.

Random (or unbiased) errors in the flow data have a different impact on load estimates. The U.S. Geological Survey (USGS) characterizes flow data (the data used for load analyses in this report) as "excellent" or "good", indicating that 95% of the discharge data are within 5% or 10% of the true value (USGS 1996). Typical precision for USGS flow data is estimated at ±3–5% (Dileanis 1997). While it is apparent that the error or uncertainty in flow data contributes to error in the load estimates for a specific event or day, it has relatively little impact on estimates of annual loads or long-term average loads. This is because the errors are random and average out over the long term. If the errors in flow data are truly random, they are incorporated into the mass loading model by contributing part of the residual model error.

Annual and Seasonal Variability

Seasonal and annual variability in flows will affect loading estimates in several ways. Annual variations in precipitation patterns and flows are generally fairly consistent throughout the watershed for a particular year. However, to the degree that annual variations affect regions differently, these differences will also affect the relative mercury loads from these regions of the watershed. The effect of seasonal and annual variations in flows will have the greatest affect on relatively constant mercury sources, such as the Sacramento Regional Wastewater Treatment Plant. The impact of constant mercury sources increases during seasonal low flows and in low water or drought years, and conversely, their relative impact on loading will be less in high flows and high water years. This is true for both total mercury loads and for bioavailable mercury.

Although a specific source may contribute a relatively greater proportion of mercury loads in low water years and during low flows, these are also the conditions when the absolute mercury concentrations have been observed to be the lowest and the probability of compliance with water quality-based criteria (based on total mercury) is expected to be high. In addition, it is the high flows experienced during relatively wet years (e.g. Water Years 1995 and 1997) that are critical for both mercury loading and compliance with water quality criteria. Seasonal and annual differences in flows are expected to result in some short-term variability in the relative importance of mercury sources. However, the conclusions of this study are largely unaffected because they are based on estimates of long term average mercury loads.

Analytical and Sampling Error

The impact of analytical or sampling errors on the loading estimates are analogous to the impact due to errors in flow measurements. A systematic bias in sampling or analytical results—either an overestimate or an underestimate in mercury concentrations—would result in a similar bias in loading estimates. To avoid this type of bias, water quality samples for this study were collected as depth-integrated cross-sectional composites at most sites, or as mid-depth grabs for well-mixed narrower flows (e.g. South and Middle Forks of the Yuba River, and Englebright Reservoir outflows). Sampling procedures and locations were selected for the specific purpose of avoiding bias due to unrepresentative water quality samples. Similarly, laboratory Quality Assurance procedures assured that no systematic bias was introduced by water quality analytical methods.

Random errors in water quality analytical data (due to sampling methods or laboratory analyses) will have a significant affect on the load calculated for a specific event or day and will contribute to the overall error of the mass loading model. As long as these errors are truly random and not biased for a specific monitoring location, they should not cause any systematic bias in the loading estimates. Sampling and analytical procedures were consistent for all the monitoring locations, so any uncertainty attributable to sampling or laboratory analytical procedures should be distributed evenly among the water quality data for all locations.

Summary of Mass Loading Analysis Uncertainty

Although there are a number of potential sources of error associated with the mass load estimates in this study, the uncertainty attributable to these errors does not appear to invalidate the primary conclusions of the study. The following evaluations were performed to evaluate the method used to estimating mercury loads:

- Estimates of long-term average flows balanced to within 1% with long-term average flows and loads calculated for the Sacramento River at Freeport. Mass loads from contributing main tributaries did not exceed Freeport loads and balanced to within 8%.

- For Water Year 1995, flows balanced to within 2%, with flows and loads calculated for the Sacramento River at Freeport. Mass loads from contributing main tributaries did not exceed Freeport loads and balanced to within 3%.

	Contributing Tributaries			
	Feather River at Verona	Sacramento River at Verona	American River	Sum (Freeport = 100%)
Avg. Annual Flow	33%	52%	16%	101%
Avg. Annual Load	25%	61%	6.4%	92.4%
WY '95 Flow	37%	47%	18%	102%
WY '95 Load	31%	58%	8.5%	97.5%

- Based on 95% confidence limits, errors for estimates of mass loads and relative loading percentages for all stream reaches in Water Year 1995 were less than 6% of the total Sacramento River load at Freeport. For stream reaches that contributed less than 10% of Sacramento River flows at Freeport, errors for estimates of mass loads and relative loading percentages were less than 1.5% of the total mercury load at Freeport. Although 95% confidence limits could not be directly calculated for estimates of average annual loads, it seems reasonable to conclude that uncertainty associated with these estimates is of a similar relative magnitude, based on the similar flow and mass balance results noted above.

The results of these evaluations suggest that there was no substantial systematic error in the method used to calculate average annual mass loads. On the basis of these evaluations, it was concluded that the loading estimates resulting from these analyses were sufficiently reliable to support the conclusions of this study.

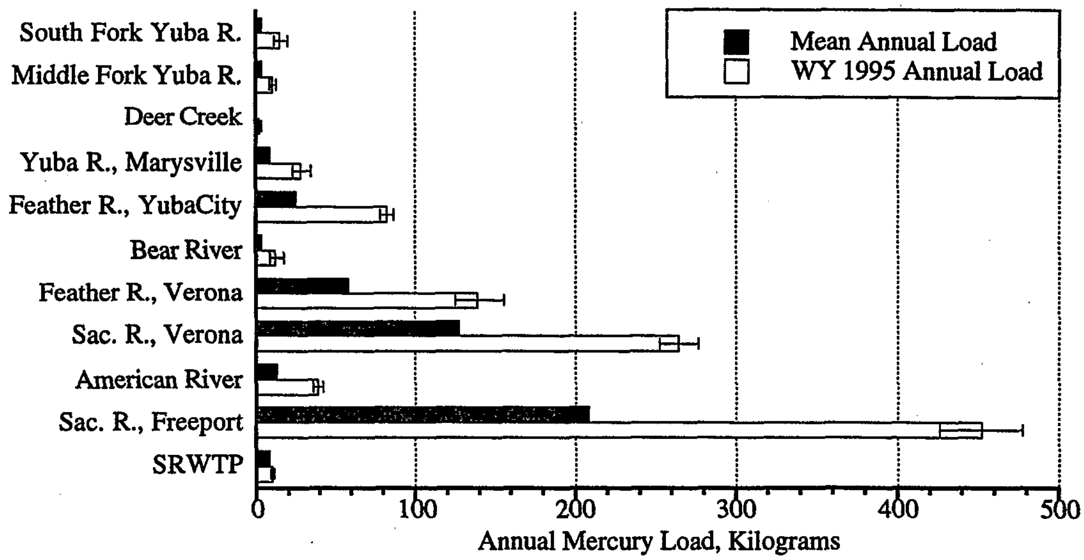


Figure 3. Sacramento River Watershed Mercury Loading: Estimated Average Annual Loads, and Estimated Total Loads for Water Year 1995 (±95% Confidence Limits)

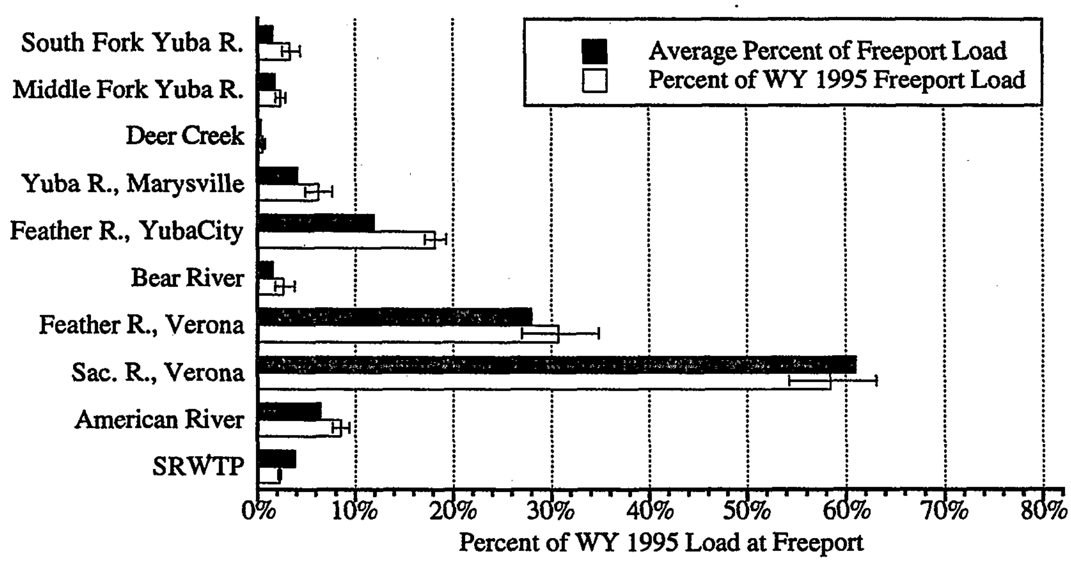


Figure 4. Estimated Percent of Total Annual Mercury Load at Freeport: Percent Average Annual Load, and Percent Water Year 1995 Load (±95% Confidence Limits)

Table 1a. Estimated Average Annual Mercury Loads: Tributaries and Reaches of the Sacramento River (Kilograms of Total Mercury).

Rank (1)	River Segment or Tributary	Estimated Mercury Load: kilograms	Estimated Mercury Load: Percent Avg. Freeport Load	Percent Avg. Freeport Flow
1	Sacramento River at Freeport (3)	208	100%	100%
2	Sacramento River above Verona	127	61	52
3	Feather River above Verona	58	25	33
4	Feather River at Yuba City	29	12	20
5	American River (3)	13	6.4	16
6	Sacramento Regional WTP	9.9	4.8	1.1
7	Yuba River at Marysville	8.5	4.1	10
8	South Fork Yuba River	3.2	1.5	1.9
9	Bear River (4)	3.2	1.5	1.7
10	Middle and North Forks Yuba River	3.6	1.7	8.0

Table 1b. Estimated Water Year 1995 Mercury Loads: Tributaries and Reaches of the Sacramento River (Kilograms of Total Mercury).

Rank (1)	River Segment or Tributary	Estimated Mercury Load: kilograms [95% C.I.] (6)	Estimated Mercury Load: Percent Freeport load [95% C.I.]	Percent WY'95 Freeport Flow
1	Sacramento River at Freeport (3)	452 [426–477]	100%	100%
2	Sacramento River above Verona	264 [253–277]	58 [54–63]	47
3	Sacramento River to Yolo Bypass (5)	167 [160–175]	37 [34–41]	34
4	Feather River above Verona	139 [125–156]	31 [27–35]	37
5	Feather River at Yuba City	82 [78–87]	18 [17–19]	25
6	American River (3)	39 [35–42]	8.5 [7.7–9.4]	18
7	Yuba River at Marysville	28 [23–34]	6.2 [4.8–7.6]	12
8	South Fork Yuba River	15 [11–20]	3.3 [2.5–4.4]	3.0
9	Bear River (6)	12 [8–17]	2.6 [1.8–3.8]	2.2
10	Middle and North Forks Yuba River	10 [8–13]	2.2 [1.8–2.8]	8.7
11	Sacramento Regional WTP	9.9 [8.8–11.2]	2.2 [2.1–2.3]	0.7

(1) Relative rank of river segment based on average annual mercury load estimate.
(2) Mass load below Verona is estimated as the sum of the loads in the Sacramento River and Feather River above Verona. The sum of these mass loads is greater than the load estimated for the Sacramento River at Freeport and may reflect flows and mercury loads diverted into the Yolo Bypass.
(3) Calculated from AMP water quality data (LWA 1996).
(4) Based on an assumed water quality similar to South Fork of Yuba River.
(5) Sacramento River loads to Yolo Bypass over the Fremont Weir, above Verona. Flows in the Yolo Bypass re-enter the Sacramento River below Freeport through Cache Slough, near Rio Vista.
(6) 95% Confidence Interval.

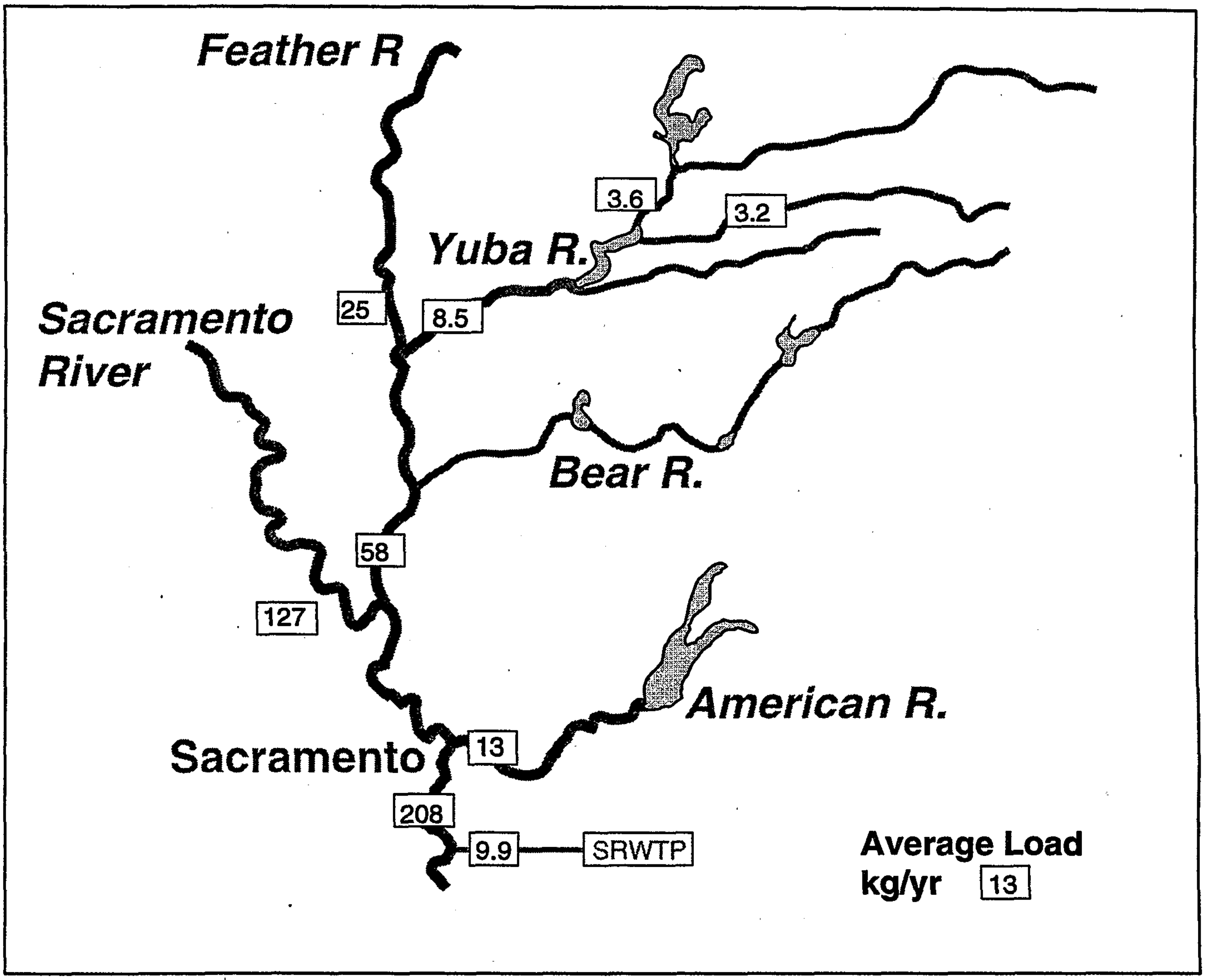


Figure 5. Mercury Loads in the Sacramento River: Estimated Average Annual Mass Loads (kg) In Main Tributaries

Reservoir Effects

Water quality data for Englebright Reservoir inflows and outflows are summarized in Table 2. Water quality for Englebright Reservoir inflows are presented as flow-weighted averages of results for the Middle and North Forks and the South Fork of the Yuba River to allow direct comparison to reservoir outflow water quality.

Concentrations of suspended solids (TSS) and total mercury were generally lower in the outflow from Englebright Reservoir than in the combined inflows to the Reservoir. When these differences in water quality were tested using Analysis of Variance (ANOVA) methods, they were found to be statistically significant at the 90% confidence level ($p<0.10$), but not at the 95% confidence level ($p<0.05$). Concentrations of dissolved mercury and methylmercury, and total methylmercury did not exhibit consistent (or statistically significant) differences in Englebright Reservoir outflow and inflows. These results suggests that the reservoir may be acting as a sink for suspended solids and mercury associated with particulates, thereby reducing mass loading from the Yuba River watershed. Differences in mercury and TSS concentrations were more dramatic during higher flows (see Appendix A, Figure A-5). This suggests that Englebright Reservoir has a more substantial effect on mercury loads during the wet season when flows and mercury loads are greatest.

Table 2. Effects of Englebright Reservoir: Water Quality in Outflows vs. Flow-Weighted Average Inflow

Parameter (units)	Count (1)	Inflow (2)	Outflow (3)	Change (4)	% Change (5)	p-value (6)
total Hg (ng/L)	10	3.1	2.2	-0.89	-29%	.0976
0.2µ filtered Hg (ng/L)	10	1.3	1.5	+0.21	+17%	.7079
total MeHg (ng/L)	7	0.035	0.040	+0.005	+14%	.2973
0.2µ filtered MeHg (ng/L)	7	0.026	0.020	-0.006	-23%	.9681
TSS (mg/L)	10	4.6	4.0	-0.60	-13%	.0999

(1) Number of sample events.
(2) Median flow-weighted inflow concentration.
(3) Median outflow concentration.
(4) Difference between median inflow and outflow water quality.
(5) Percent difference between median inflow and outflow water quality.
(6) "p-value" is a measure of the statistical significance of differences in water quality. The p-value is the probability of observing the same difference in a normally distributed random sample; e.g. a p-value of 0.05 represents a 1-in-20 chance (i.e. the 95% confidence level) that the observed difference in water quality is due to random chance alone, while a p-value of 0.10 represents a 1-in-10 chance (i.e. the 90% confidence level) that the observed difference in water quality is due to random chance alone. A p-value of 0.05 (95% confidence level) is commonly used as the limit for statistical significance.

Biota

Data from the biota sampling portion of the study consisted of total mercury concentrations in tissue, and species and trophic level information for each sampling location. Trophic level information consisted of a description of the role of each genus or species in the aquatic food web (e.g. herbivore, scavenger, small predator, large predator, etc.). This trophic level information was broadly categorized by the relative position in the food chain (i.e. who eats who) and each category was assigned a "relative trophic level" between 0 and 5, with the highest values representing top predators.

Biomagnification

Mercury concentrations in biota typically exhibit a phenomenon termed "biomagnification". This means that upper trophic level species (i.e. species that are higher on the food chain) and older individuals accumulate higher tissue concentrations of mercury by consuming lower trophic level species. For the purpose of this study, biomagnification may result in biased estimates of average tissue concentrations because biota collections for each sampling location are not evenly distributed among the range of trophic levels. To correct for this potential bias and to allow direct comparisons between sampling locations, tissue concentrations were normalized to an intermediate trophic level for each sampling site.

Normalization of tissue concentrations was accomplished by a multi-step process. First, an analysis of covariance (ANCOVA) was performed to verify and quantify the effect of biomagnification on mercury concentrations for each sub-drainage. The results of the ANCOVA were then used to normalize mercury concentrations to the same intermediate trophic level for each site. (The selection of the specific intermediate trophic level for normalization is arbitrary and does not bias comparisons between sites.) The normalized mercury data were used to calculate average tissue concentrations for each sub-drainage. Finally, the sub-drainages were ranked by average tissue concentration to identify "hot spots" of mercury bioaccumulation. Important results of these analyses are summarized in Table 3 and discussed below.

As expected, the ANCOVA results confirmed that tissue concentrations of mercury increased with increasing trophic levels. This relationship between trophic level and mercury tissue concentrations appeared to be similar for all sampled sites and is consistent with mercury biomagnification through the food chain.

Hot Spots

Based on average tissue concentrations of mercury, four sub-drainages exhibited greater bioaccumulation of mercury and were categorized as "bioavailable mercury hot spots". Biota collected from (1) the Middle Fork of the Yuba River (above the confluence with the North Fork), (2) the South Fork of the Yuba River, (2) the Deer Creek tributary of the

Yuba River, and (4) the Bear River were found to have average tissue mercury concentrations approximately 2 to 3 times higher than concentrations observed in Feather River biota, and 3 to 4 times higher than observed in biota collected from the American River watershed. Of the sites sampled specifically for this project, the South Fork of the Yuba River exhibited the highest overall levels of mercury bioaccumulation.

For the drainages characterized as bioavailable mercury "hot spots", no specific sites or stream reaches stood out as individual hot spots. This suggests that mercury sources are relatively diffuse within these drainages (i.e. mercury sources are not highly localized). In each of the drainages, biota collected from headwater sites typically had lower tissue mercury concentrations than downstream sites on the same stream.

Table 3. Mercury Bioaccumulation in Biota Collected from Sierra Streams: Sub-Drainages Ranked by Average Tissue Mercury Concentrations.

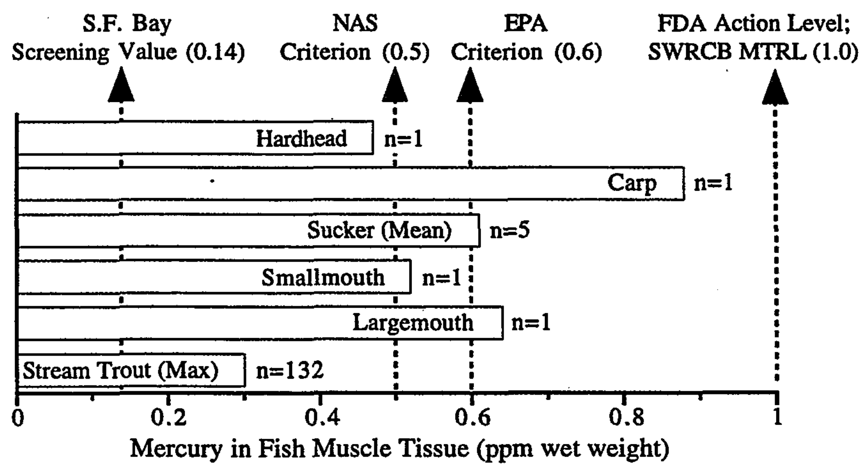
rank (1)	watershed (2)	sub-drainage (3)	mean mercury, mg/kg in tissue (4)	std. dev. (5)	count (6)
1	Bear River	not applicable	.326	.159	22
2	Yuba River	Deer Creek	.253	.102	6
3	Yuba River	South Fork	.237	.093	24
4	Yuba River	Middle Fork	.204	.091	21
5	Yuba River	North Fork	.140	.059	14
6	American River	below Folsom Lake	.130	.007	3
7	Feather River	Middle Fork	.125	.096	22
8	Yuba River	below Englebright Res.	.110	.039	4
9	Feather River	North Fork	.104	.063	30
10	American River	South Fork	.073	.022	11
11	American River	Middle Fork	.069	.038	12
12	Fall River	not applicable	.067	.022	7
13	Feather River	below Lake Oroville	.062	.026	4
14	American River	North Fork	.045	.006	4
15	Feather River	South Fork	.038	.008	7

(1) "rank" is the relative ranking by mean tissue mercury concentration of each sub-drainage.
(2) "watershed" identifies the primary watershed from which the invertebrates were collected.
(3) "sub-drainage" identifies the specific stream segment where invertebrates were collected.
(4) "mean mercury" is the average tissue concentration of mercury (mg/kg dry tissue weight) for each sub-drainage. This value is normalized to an intermediate trophic level to allow unbiased comparison between sub-drainages.
(5) Standard deviation of the normalized tissue mercury concentrations.
(6) Number of samples analyzed.

Reservoir Effects

Reservoirs appear to have an effect on mercury bioaccumulation at downstream river sites. Tissue concentrations of mercury in biota collected above and below Englebright Reservoir suggest that the reservoir had the effect of lowering bioavailable mercury concentrations in downstream waters. This result was consistent with the water quality data for Englebright Reservoir, which suggested that the reservoir had the effect of reducing total mercury concentrations. Biota collected below other reservoirs (e.g. Folsom Lake on the American River, Lake Spaulding on the South Fork of the Yuba River, and Rollins Reservoir on the Bear River) generally had consistently lower tissue mercury concentrations than biota collected above these reservoirs in the same watershed. However, great care should be taken in extrapolating the results observed for Englebright Reservoir (or any other reservoir) to all foothill reservoirs: flow regimes, water temperatures, reservoir morphology, reservoir management, mercury loading and other factors affecting mercury transport and bioaccumulation will be substantially different at other reservoirs. The effects of annual and seasonal variations in water years have also not been adequately investigated, and there is currently insufficient information to predict the effects of these and other parameters on mercury loading and bioaccumulation in other foothill reservoirs.

While some foothill reservoirs may reduce average bioavailable downstream, it appears that bioavailable mercury was increased within Englebright Reservoir in comparison to upstream sites. The tissue concentrations observed in fish collected from Englebright Reservoir are much higher than those observed in trout collected from streams upstream from the reservoir. Because only a few specimens were collected (n=9), and none of these were trout, these results are not strictly comparable with the remainder of the fish data in the upper watershed. However, the data are consistent with earlier observations of higher concentrations of mercury in fish from foothill reservoirs than at upstream sites (SWRCB 1993).



Mercury in Englebright Reservoir Fish and Sierra Stream Caught Trout

The results of this study suggest the need for additional data collection and risk assessment investigations to evaluate mercury-related health risks in Sierra foothill reservoirs. Several fish collected from Englebright Reservoir for this study exceeded NAS and CDHS guidelines (0.5 ppm tissue mercury) and USEPA (1993) screening values (0.6 ppm tissue mercury), and in some cases approached the SWRCB (1993) Maximum Tissue Residue Level and FDA action level for mercury (1.0 ppm tissue mercury). Levels in all fish were also well in excess of the more conservative health risk screening value (0.14 ppm tissue mercury) used in the recent San Francisco Bay fish tissue study (SFRWQCB 1995). Of these tissue mercury guidelines, only the FDA action level (1.0 ppm) and the NAS guideline (0.5 ppm) currently have any regulatory force. The screening values used by the San Francisco Bay Regional Board (SFBRWQCB) were developed in accordance with guidelines published by USEPA (1993), and are used expressly to identify pollutants of concern. Exceedance of the SFRWQCB screening value is an indication that "...more intensive site and species-specific monitoring and/or evaluation of human health risk be conducted" (SFBRWQCB 1995). On the basis of these preliminary data, it appears that there is a real potential for mercury-related health risks in Sierra foothill reservoirs. While conclusively addressing mercury-related health risks will require an extensive risk assessment investigation that is beyond the scope of this study, it is recommended that comprehensive fish sampling be performed in Sierra foothill reservoirs as a first step to provide more definitive answers about mercury-related health risks and the need for any regulatory action.

SUMMARY

The principal findings of the biota and water quality monitoring elements of this study are as follows:

- The majority (approximately 60%) of the estimated total average annual mercury load in the Sacramento River at Freeport is contributed by the Sacramento River above Verona. Estimated mercury contributions from the other main tributaries of the Sacramento River (Feather River, Yuba River, Bear River, and American River) range from less than 2% to 11% and total approximately 25%. The mass load from the Sacramento Regional Wastewater Treatment Plant is equivalent to approximately 5% of the mercury load estimated for Freeport.

- Data from the biota and water quality monitoring elements of this study provided generally consistent results. Both water quality and biota results indicate that the Feather River and American River watersheds were relatively low in total and bioavailable mercury concentrations. Both data sets indicate that the South Fork of the Yuba River watershed is a relative "hot spot" for mercury concentrations in water and biota within the study area.

- However, tissue concentrations appear to be elevated throughout the South Yuba River watershed, indicating that mercury sources are widely distributed in this drainage. This relatively diffuse pattern of mercury source distribution appears to be the case for all of the study area drainages investigated.

- Total mercury concentrations and bioavailable mercury were reduced in outflows from Englebright Reservoir relative to inflows. Bioavailable mercury was also generally lower below a number of other foothill reservoirs.

- Based on limited fish tissue data from Englebright Reservoir and previous studies, Sierra foothill reservoirs appear to have the potential for significant mercury-related health risks. It is recommended that additional comprehensive data collection be performed in Englebright Reservoir and other foothill reservoirs to further evaluate the potential risk to human consumers of fish.

IMPLEMENTATION PLAN AND CHECKLIST

In this section, methods for evaluation of alternative control strategies are described and a control strategy for reduction of mercury loading to the Sacramento River is recommended. A preliminary implementation plan for the selected control strategy is presented.

EVALUATION OF MERCURY SOURCE CONTROL STRATEGIES

The majority of successful mercury source control strategies which have been employed currently or historically were developed to control point sources of mercury such as active and inactive mercury mines, chlor-alkali plants, pulp mills, power generation facilities, various industrial dischargers, and municipal wastewater treatment plants (Table 4). Most of these controls were developed in response to regulation of specific facilities or industries. With the exception of reformulation of a number of domestically used products, few source control strategies have specifically targeted mercury loading from nonpoint sources. Some strategies developed specifically as controls of nonpoint sources of other pollutants may also be effective as controls for some sources of mercury (e.g. stormwater detention basins, fossil fuel emission controls). To date, no controls have been developed to target natural nonpoint sources of mercury such as exist in the Sacramento River watershed.

Table 4. Mercury Sources And Controls Employed Or Suggested By Others.

source or source category	control strategy	reference
mercury, gold, and base metal mines (active and inactive)	various preventative, segregative, and mitigative controls for mine drainage	LWA 1993
coal- and oil-fired power plants	emission controls and regulations; coal cleaning	Chu and Porcella 1995; Neme 1991
chlor-alkali, vinyl, and acetaldehyde production facilities	process redesign; emission controls and regulations	CVRWQCB 1987
other industrial dischargers	pretreatment programs and requirements; recycling of mercury-containing products;	
municipal wastewater facilities	wastewater treatment; biosolid incinerator emission controls; redesign of biosolid incinerator processes	Balogh and Liang 1995
paper and pulp mills	discontinued use of mercury-based "slimicides"	CVRWQCB 1987
agriculture	changes in formulations and use of fungicidal seed treatments; regulation of Hg concentrations in reclaimed effluent biosolids applied to fields	CVRWQCB 1987
contaminated reservoir and estuarine sediments	dredging; sediment "capping"	
urban runoff	detention basins for control of sediments and associated pollutants;	
domestic sources (paints, preservatives, pharmaceuticals)	"delisting" of mercury-based compounds; product reformulation	CVRWQCB 1987

Of the successful mercury source control strategies currently in use, those related to prohibition of specific products or formulations, specific industrial processes and discharges, urban runoff, and atmospheric emissions were not considered appropriate or feasible for the primary sources of mercury in the Sacramento River watershed. Some technologies developed for control of contaminated sediments and mine drainage impacts appear feasible for the study area and these were evaluated further. The seven specific source control strategies evaluated for use in the study area are summarized below.

Reclamation of mine tailings: This strategy consists of the stabilization and containment of exposed tailings from historic hydraulic and instream mining operations. The goal of this strategy would be to limit erosion and transport of mine tailings and associated mercury into area streams.

Removal of mine tailings: This strategy consists of the removal and disposal or storage of localized riparian zone deposits of tailings from historic hydraulic and instream mining operations.

Removal of instream mercury-enriched sediments: This strategy consists of the dredging and disposal of instream mercury-enriched sediments.

Reservoir operational changes and reservoir dredging: These two related strategies are evaluated separately. They consist of (1) changes in the operation of major reservoirs to maximize deposition of sediment and associated mercury from the water column, and (2) dredging and disposal of mercury-enriched sediments from major reservoirs.

Water treatment: This alternative is analogous to mitigative treatment of mine drainage not controlled by preventative or segregative methods and consists of the treatment of study area surface waters to remove mercury.

Additional regulation of gold mining activity: While current gold extraction methods do not introduce additional mercury into the watershed, instream dredging and reworking of existing mine tailings may cause or promote resuspension and transport of mercury already in the system. This alternative includes limitation or prohibition of instream and riparian zone gold mining operations, or additional regulation of gold mining methods, primarily to limit resuspension or introduction of mercury-containing sediments in study area streams.

Mercury recycling program: This alternative consists of recovering easily accessible and environmentally mobile elemental mercury by providing effective incentives for mercury recovery by volunteer program participants. Mercury collected from these volunteers would be sold to commercial recycling operations. Recreational and commercial gold dredgers active in the region are expected to be the principal participants.

Evaluation Criteria

The following criteria were used to evaluate the control strategy alternatives. These criteria are summarized in Table 5.

Accessibility of Mercury: Where (and in what form and concentrations) is mercury accessible in the study area? Is mercury localized and concentrated or diffuse and widely distributed? For the purpose of source control evaluations, mercury present in the study area was partitioned into the following categories:

- Elemental mercury (i.e. quicksilver), present primarily among streambed sediments near or downstream from historical mining areas.
- Particulate (sediment-bound) inorganic mercury associated with riparian zone or instream sediments.
- Particulate and dissolved mercury in the water column.
- Mercury in biota.

Source Data Sufficiency: Are available data for mercury sources sufficient to implement the control strategy? Are additional data required?

Limitations of Controls: What are the primary factors limiting the effectiveness of the control strategy? How severely do these factors limit effectiveness?

Potential Benefits of Control Strategy: What are the expected benefits (both in the study area and in the Sacramento River downstream) of implementing the control strategy. Specifically:

- What is the estimated percentage of mercury loads removed (or controlled) by source control(s)?
- Would implementation of the controls result in significant increases in beneficial uses?

Potential Impacts of Source Controls: Are there potentially significant environmental or economic impacts associated with control strategy implementation? How severe are the expected impacts?

Costs: What is the expected relative cost of the mercury control strategy? Is the expected cost per kilogram of mercury controlled higher or lower than for other strategies?

Relevance Outside of the Study Area: Can implementation of the source control be considered a realistic pilot or demonstration project for other watersheds? More specifically:

- Can the control strategy be applied outside the study area?
- What specific factors or conditions are required (if any) for success of the control strategy?
- Will implementation of the strategy as a pilot or demonstration project provide new information useful for evaluating the application of the strategy elsewhere?

Table 5. Summary of Control Strategy Evaluation Criteria Used in This Study.

evaluation criterion	Control Strategies 1 (best)	2	3 (worst)
% of in-place Hg sources removed or controlled	> 50%	25 - 50%	0%
Is Hg source data sufficient to implement strategy?	existing information is sufficient	some additional data are needed	extensive additional data needed
Limitations of strategy	minor	moderate	severe
impacts: environmental and economic impacts of implementation in study area	no significant impacts expected	potentially significant impacts expected	severe environmental or economic impacts expected
decrease in study area Hg loads and concentrations	significant decrease in Hg (> 25%)	moderate decrease in Hg (< 25%)	no long-term decrease in Hg expected
increase in study area beneficial uses	probable significant increase in uses supported	minor increase in uses supported possible	no net increase in uses supported expected
decrease in Sacramento River Hg loads	significant decrease in Hg (> 5%)	minor decrease in Hg (< 5%)	no long-term decrease in Hg expected
increase in Sacramento River beneficial uses	significant increase expected in uses supported	possible increase in uses supported	no increase expected
relative cost per unit of mercury controlled	low cost per kg of mercury controlled	moderate cost per kg of mercury controlled	high cost per kg of mercury controlled
value as pilot or demonstration project	(a) implementation would provide new information valuable in evaluating controls for other regions AND (b) control strategy widely applicable elsewhere	(a) implementation would provide new information valuable in evaluating controls for other regions AND (b) limited applicability of control strategy elsewhere	(a) implementation would NOT provide new information valuable in evaluating controls OR (b) control strategy NOT applicable elsewhere

Recommended Mercury Control Strategy

Of the selected mercury control strategies, none stands out as a clearly superior alternative. Because (1) the overwhelming majority of mercury loading appears to be contributed by the Sacramento River upstream from the confluence with the Feather River, and (2) mercury sources in the study area appear to be diffusely distributed without any significant "hot spots", none of the control strategies are expected to result in substantial water quality improvements or increases in beneficial uses in the lower Sacramento River. In addition, the impact of any control strategies implemented in the study area are further limited in that they don't effectively address mercury loading from atmospheric deposition, which may constitute a significant percentage of the total mercury load in the Feather and Yuba River watersheds. These factors combine to indicate that a complete evaluation of mercury source control strategies for the Sacramento River will require additional consideration of mercury sources on the West Side of the Sacramento Valley. There are currently two studies (the USGS NAWQA study of Sacramento River water quality and the U.S. Geological Survey's metals transport study) in progress that may shed additional light on the relative importance of these mercury sources to the Sacramento River. The results of these studies should be considered—and possibly supplemented to isolate major discrete sources—in the process of developing and evaluating comprehensive mercury control strategies for the Sacramento River.

Although the control strategy evaluations did not result in the unqualified recommendation of any individual control, the mercury recycling program alternative appears to have unique merits that warrant further exploration. Unlike all of the other alternatives, a recycling program would not require additional mercury source data to be effectively implemented, and moreover, may provide additional data regarding the distribution of mercury throughout the study area. Implementation of this alternative is not expected to result in any significant local environmental or economic impacts. While it is similar to other alternatives in that it will probably have little immediate impact on total mercury concentrations and annual loads in the lower Sacramento River, it has the advantage of permanently removing measurable amounts of the most accessible and environmentally mobile form of mercury from the upper watershed, much of it directly from instream sediment and cobble. Because it is critical to protect local watersheds in their own right (as well as the Delta), an important potential benefit of this program is the reduction of mercury loads to local Sierra foothill reservoirs, where health risks due to mercury bioaccumulation appear to be most probable in the region. It is expected that a mercury recycling program would be the least costly of the alternatives and would result in the lowest cost per kilogram of mercury removed from the watershed. Although there are few other historical mercury or gold mining regions that currently support small-scale mining activity at the levels occurring in the study area, a mercury recycling program could serve as a model for agency and special interest group cooperation in resolving other watershed related issues.

On the basis of the factors cited above, it is recommended that development and implementation of a mercury recycling program be further considered as the preferred initial control strategy for reducing mercury loads in the Sacramento River watershed. This alternative appears to provide the most cost-effective immediate and long-term reductions of mercury loading from the study area. Although other strategies may address a larger proportion of study area mercury stores or provide marginally greater reductions in Sacramento River mercury loads, these alternatives were associated with extremely high costs or severe environmental impacts. In contrast, a mercury recycling program is a relatively low-cost alternative that would not result in significant environmental impacts, if properly managed. A recycling program would result in immediate measurable and trackable benefits (in the form of kilograms of recovered mercury) while providing opportunities for public education and public relations successes. The program also has the potential for developing the valuable (and largely untapped) information resource represented by the cumulative knowledge of the recreational and commercial gold mining community active in the watershed.

A summary of the results of control strategy evaluations is presented in Table 6. Individual evaluations and discussion of the selected control strategies are presented in Appendix C.

Table 6. Summary of Control Strategy Evaluations.

	Control Strategies							
evaluation criteria	Hg recycl ing	tailings reclama-tion	tailings removal	stream channel dredging	reservoir dredging	reservoir operation changes	H_2O treatment facilities	mining regula-tion
% of in-place Hg sources removed or controlled	2	3	2	3	3	3	3	3
Is Hg source data sufficient to implement strategy?	1	2	2	3	2	1	1	1
limitations of strategy	2	2	2	3	3	3	2	3
impacts of implementation in study area	1	1	3	3	3	3	2	3
decrease in study area Hg loads and concentrations	2	2	2	3	3	3	3	3
increase in study area beneficial uses	3	2	3	3	3	3	3	3
decrease in Sacramento River Hg loads	2	2	2	3	3	2	2	3
increase in Sacramento River beneficial uses	3	3	3	3	3	3	3	3
relative cost per unit of mercury controlled	1	2	3	3	3	3	3	3
value as pilot or demonstration project	2	2	3	3	3	3	3	3
unweighted average:	**1.9**	**2.1**	**2.5**	**3**	**2.9**	**2.7**	**2.5**	**2.8**

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C-035524

Mercury Recycling Program Elements

The Central Valley Regional Water Quality Control Board (CVRWQCB) and the State Water Resources Control Board Non-Point (SWRCB) are in the process of developing a mercury and lead recovery project modeled after hazardous waste recycling programs already in use throughout the state. The proposed control strategy is based on the CVRWQCB/SWRCB mercury and lead recovery project, and would optimally be integral with this project. The essential elements of the proposed control strategy are an effective public outreach and education program, a cooperative relationship between participating agencies and the recreational and commercial gold mining community, and an efficient organizational structure for collecting and transporting recovered mercury to commercial recyclers. The principal features of the program elements, a preliminary institutional plan, and funding alternatives are presented below. In addition, it is recommended that baseline monitoring be performed in local streams and Sierra foothill reservoirs to evaluate the effectiveness of the program in reducing mercury loads and local health risks. If this recommendation is adopted, the monitoring program could also serve as the basis for further evaluating potential mercury-related human health risks in the region.

Public Outreach and Education

This element of the mercury recycling program would focus on the expected primary participants in the program (recreational and commercial gold miners/dredge operators). The purpose of this element would be to present the proposed mercury recovery program, with the particular emphasis that mercury is a valuable recyclable resource. The educational efforts should emphasize the cooperative nature of the program and explain the incentives to the participant and the benefits to the watershed.

The educational element of the recycling program would be implemented in two phases. The initial phase would contact a representative cross-section of potential participants to present the proposed program and to identify the needs and concerns of those participants. This information would be used to refine the elements of the program (e.g. incentives for recycling, preferred collection methods and schedules, and most effective education alternatives) and to address the concerns of participants, with the ultimate goal of maximizing participation and mercury recoveries. The second phase of the educational element would be to distribute information and details of the final program more extensively among the anticipated participants. An additional public relations facet of the program would follow up by presenting the results and benefits of the program to the broader public.

There are wide range of options for implementing an effective public education element of the mercury recycling program. Strategies for education and dissemination of program information could be employed singly or in combination. Alternatives for educational efforts include (but are not limited to) the following:

- field outreach efforts;
- articles or advertisements in periodicals or newsletters serving recreational and commercial gold miners;
- advertisements, informational materials, or displays at businesses serving the recreational and commercial mining community;
- incorporation of program information into mining permit application materials;
- presentations at events or conferences attended by gold dredgers.

Mercury Collection and Recycling

The primary purpose of this element of the program is to receive recovered mercury and transport it to selected commercial mercury recycling facilities. It is essential to this phase of the program to develop appropriate health and safety plans for the recovery, collection, storage, and transport of the mercury, as well as to obtain the appropriate permits for these activities. The collection operation would also provide a financial incentive for participation in the program, based on the current market value for recovered mercury. This element would also serve to collect valuable information about where the mercury was recovered, as well as the location of mine tailings or other substantial deposits of mercury. This information could be used to identify "hot spots" and potentially to direct more focused mercury controls or intensive recovery efforts in the watershed.

Alternatives for collection operations include (1) centrally located mercury collection sites, (2) a field collection program, and (3) cooperative agreements with local smelting operations or commercial mercury recyclers. Centrally located mercury collection sites could be located at the offices of participating agencies or with businesses serving the mining community. Collection operations at central locations or in the field could be continuous or scheduled periodically (e.g. to coincide with the end of the mining "season" defined by seasonal restrictions or prohibition of instream dredging operations). These alternatives could be implemented singly or in combination to provide the most effective mercury collection system. Selection of final implementation options would be based in part on the results of the initial phase of the public education element.

Institutional Plan

A mercury recycling program will require cooperation among state and federal agencies, county governments, the California Department Fish and Game, and gold dredge operators. The preliminary institutional plan for the proposed recycling program considers the regulatory agencies affected by the program, identifies potential institutional constraints and solutions, and recommends an agency to implement the program.

Agencies and special interest groups that have an interest in participating in the program, or that would be consulted to resolve specific constraints to program implementation are listed in Table 7. Potential roles are identified and summarized for the affected agencies and groups.

Table 7. Affected Agencies and Participants, and Potential Roles in the Proposed Mercury Recovery Program.

Agency	Primary Project Roles
Central Valley Regional Water Quality Control Board	Recommended as the primary implementing agency; The CVRWQCB would be responsible for initiating and implementing the program.
State Water Resources Control Board	Assist CVRWQCB in program coordination and implementation
California Department of Fish and Game	Assist in program promotion by providing information with gold dredging permits; Offices may serve as collection points sites;
U.S. Forest Service	Field offices may serve as collection points sites; Can provide program guidance for handling material classified as hazardous waste;
U.S. Bureau of Land Management	Field offices may serve as convenient collection points; Experience in handling hazardous waste under CERCLA can provide program guidance;
California Mining Association	Identify commercial operations willing to pickup, refine, and market recovered mercury; Assist in developing method for determining compensation (incentives) for program participants;
Gold Dredge and Metal Detector Operators	These are expected to be the primary volunteer participants and recovery workforce for the project. Associations could contact members directly, or through newsletters or special events to promote the program and encourage participation in the recovery effort.
Department of Toxic Substance Control	Responsible for ensuring that the program complies with applicable laws for permit requirements; Review of facilities and equipment for collection and storage of recovered mercury; Responsible for developing an explicit policy to allow participants in the program to operate effectively without undue administrative burdens (e.g. fees, permits, etc.);
California Highway Patrol, Department of Transportation, Cal EPA	These agencies have jurisdiction over transportation of hazardous materials and would be consulted in resolving transportation safety issues;
County Health Departments	May be interested in participating, reviewing, or promoting the program;

There are a number of institutional constraints to implementing the proposed mercury recycling program that will need to be addressed. Resolution of these constraints will require the cooperation of a number of agencies. The key issues include:

- Program participants should not be penalized for recovering and returning mercury. Resolution of this issue may require reclassification of mercury (probably by the Department of Toxic Substance Control) to avoid administrative burdens and penalties associated with recovery and handling of hazardous waste.

- Storage of mercury in approved safe containers at convenient central locations (e.g. Forest Service, Fish and Game, or county offices) will require permits approved by one or more agencies.
- A mechanism for compensation of participants based on the market value of the recovered material must be developed to provide incentive for participation.

Financial Plan

The majority of the costs of the proposed program are associated with development and implementation of the public outreach and educational elements. Because of the high degree of interagency cooperation required, actual program costs would depend substantially on the levels of participation and support of the participating agencies.

Funding designated specifically for the proposed program must be developed for the program to be viable. Although many of the affected agencies identified have expressed willingness to participate in a program of this type, none of these agencies have budget surpluses to allocate to the proposed project. To date, several potential funding sources have expressed an interest in the program, including:

- CALFED program
- USEPA grant funds (205(j), 319, etc.), and
- Sacramento Regional County Sanitation District (e.g. pollutant trading).

Project Implementation Schedule

A draft project implementation schedule is integrated with the Program Implementation Evaluation Checklist. The proposed schedule presents the anticipated initiation and completion dates for significant program milestones as the number of months after approval of the final implementation plan by the State Board.

IMPLEMENTATION EVALUATION CHECKLIST

An Implementation Evaluation Checklist will be used to track and evaluate project progress on an annual basis. The annual checklist will be a one-page form identifying major program milestones and the recommended schedule as documented in the final project report. An example of the proposed Evaluation Checklist is presented on the following page. The final Evaluation Checklist will reflect the approved final implementation plan.

Mercury Recycling Program Implementation Evaluation Checklist: Initial Program Year

significant program milestone	expected initiation(1)	actual initiation	expected completion	actual completion
Statements of cooperation from participating agencies and interest groups	0 months		2 months	
Final program work plan	2 months		4 months	
Informational materials for initial public outreach phase of public education program	4 months		7 months	
Implementation of initial public outreach phase of public education program	7 months		9 months	
Final collection plan	8 months		11 months	
Health and safety plans for collection facilities	8 months		11 months	
Public education materials for collection facilities	8 months		11 months	
Health and safety plans for storage facilities	8 months		11 months	
Transportation health and safety plans	8 months		11 months	
Implementation of final public outreach phase of public education program	12 months		12 months	
Implementation of mercury collection phase	12 months		NA	
Annual Project Summary Report	12 months		15 months	

(1) total time from approval of final implementation plan

Mercury Recycling Program Evaluation Checklist: Initial and Subsequent Program Years

Program Evaluation Milestones

Number of active collection sites		
Scheduled collections completed (%)		
Number of potential volunteer participants contacted		
Number of volunteer participants contributing recovered mercury		
Volume (or mass) of mercury recovered		
Value of mercury recovered		
Average mercury concentration in fish tissue: Local Streams- Reservoirs-		
Additional program evaluation criteria to be determined...		
Annual project summary report		

DATA MANAGEMENT

STATEMENT OF TRANSFER TO STORET

All water quality data have been submitted to the State Water Quality Information Services (SWQIS) for incorporation into the STORET database. Because the STORET database in its current form does not allow effective storage and retrieval of the species information critical to interpretation of the biota data, this data will be reconfigured and submitted to SWQIS when data requirements for the new version of STORET become available.

PRINTOUT OF DATA TRANSMITTED TO STORET

Sacramento River Mercury Control Planning Project water quality data transmitted to STORET are presented in Appendix F.

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APPENDIX A

WATER QUALITY SUMMARY STATISTICS AND TIME SERIES

Total Mercury (ng/L)	Mean	Std. Dev.	Count	Min	Max	Median
Yuba River below Englebright Res.	3.62	2.96	10	.920	8.68	2.18
Midldle and North Forks Yuba River	4.27	5.90	11	.680	21.61	2.07
South Fork Yuba River	21.42	27.51	13	1.06	74.86	7.29
Yuba River at Marysville	11.96	11.36	11	2.71	39.96	7.07
Feather River at Yuba City	7.59	2.64	9	4.24	11.70	7.84
Feather River. above Verona	14.47	12.38	8	5.50	42.29	9.55
Sacramento R. above Verona	30.58	43.05	8	7.24	136.29	15.95

0.2µ Filtered Mercury (ng/L)	Mean	Std. Dev.	Count	Min	Max	Median
Yuba River below Englebright Res.	1.95	1.93	10	.33	7.01	1.47
Midldle and North Forks Yuba River	1.47	1.53	11	.65	6.03	1.09
South Fork Yuba River	3.28	2.63	13	.62	8.19	1.85
Yuba River at Marysville	2.71	1.51	11	1.18	5.63	2.17
Feather River at Yuba City	2.98	3.15	9	1.08	11.17	1.86
Feather River. above Verona	2.41	1.51	8	.93	5.69	1.89
Sacramento R. above Verona	2.76	1.58	8	1.07	5.50	2.75

Particulate* Mercury (ng/L)	Mean	Std. Dev.	Count	Min	Max	Median
Yuba River below Englebright Res.	1.67	1.71	10	.45	5.65	.77
Midldle and North Forks Yuba River	2.80	4.42	11	.03	15.58	1.13
South Fork Yuba River	18.14	25.53	13	.41	66.67	4.75
Yuba River at Marysville	9.25	10.37	11	1.53	36.27	5.03
Feather River at Yuba City	4.61	2.33	9	.53	7.60	5.21
Feather River. above Verona	12.06	11.10	8	4.21	36.60	6.88
Sacramento R. above Verona	27.82	41.90	8	6.00	130.79	13.20

*estimated as total mercury concentration minus 0.2µ filtered mercury concentration

Total Methylmercury (ng/L)	Mean	Std. Dev.	Count	Min	Max	Median
Yuba River below Englebright Res.	.044	.024	7	.012	.094	.040
Midldle and North Forks Yuba River	.025	.014	8	.010	.043	.021
South Fork Yuba River	.106	.058	7	.050	.189	.104
Yuba River at Marysville	.121	•	1	.121	.121	.121
Feather River at Yuba City	.102	•	1	.102	.102	.102
Feather River. above Verona	•	•	0	•	•	•
Sacramento R. above Verona	•	•	0	•	•	•

0.2μ Filtered Methylmercury (ng/L)	Mean	Std. Dev.	Count	Min	Max	Median
Yuba River below Englebright Res.	.028	.017	7	.012	.057	.02
Midldle and North Forks Yuba River	.020	.011	8	.012	.042	.016
South Fork Yuba River	.056	.018	7	.029	.075	.062
Yuba River at Marysville	.058	•	1	.058	.058	.058
Feather River at Yuba City	.058	•	1	.058	.058	.058
Feather River. above Verona	•	•	0	•	•	•
Sacramento R. above Verona	•	•	0	•	•	•

Particulate* Methylmercury (ng/L)	Mean	Std. Dev.	Count	Min	Max	Median
Yuba River below Englebright Res.	.016	.020	7	-.017	.037	.025
Midldle and North Forks Yuba River	.005	.019	8	-.030	.031	.004
South Fork Yuba River	.050	.046	7	.010	.115	.032
Yuba River at Marysville	.063	•	1	.063	.063	.063
Feather River at Yuba City	.044	•	1	.044	.044	.044
Feather River. above Verona	•	•	0	•	•	•
Sacramento R. above Verona	•	•	0	•	•	•

*estimated as total methylmercury concentration minus 0.2μ filtered methylmercury concentration

TSS (mg/L)	Mean	Std. Dev.	Count	Min	Max	Median
Yuba River below Englebright Res.	4.50	1.90	10	3.00	8.00	3.50
Midldle and North Forks Yuba River	7.09	9.95	11	3.00	36.00	3.00
South Fork Yuba River	45.15	68.24	13	3.00	240.00	16.00
Yuba River at Marysville	16.32	11.50	11	3.00	42.00	12.00
Feather River at Yuba City	23.22	8.90	9	12.00	40.00	25.00
Feather River. above Verona	33.75	27.48	8	12.00	90.00	21.00
Sacramento R. above Verona	175.63	240.71	8	39.00	750.00	87.00

pH	Mean	Std. Dev.	Count	Min	Max	Median
Yuba River below Englebright Res.	7.32	.47	9	6.57	8.23	7.33
Midldle and North Forks Yuba River	7.39	.38	11	6.81	8.06	7.45
South Fork Yuba River	7.50	.30	13	7.11	8.05	7.53
Yuba River at Marysville	7.02	.43	10	6.42	7.60	7.15
Feather River at Yuba City	7.18	.34	8	6.42	7.50	7.23
Feather River. above Verona	7.29	.27	7	6.78	7.61	7.32
Sacramento R. above Verona	7.13	.73	6	5.73	7.84	7.27

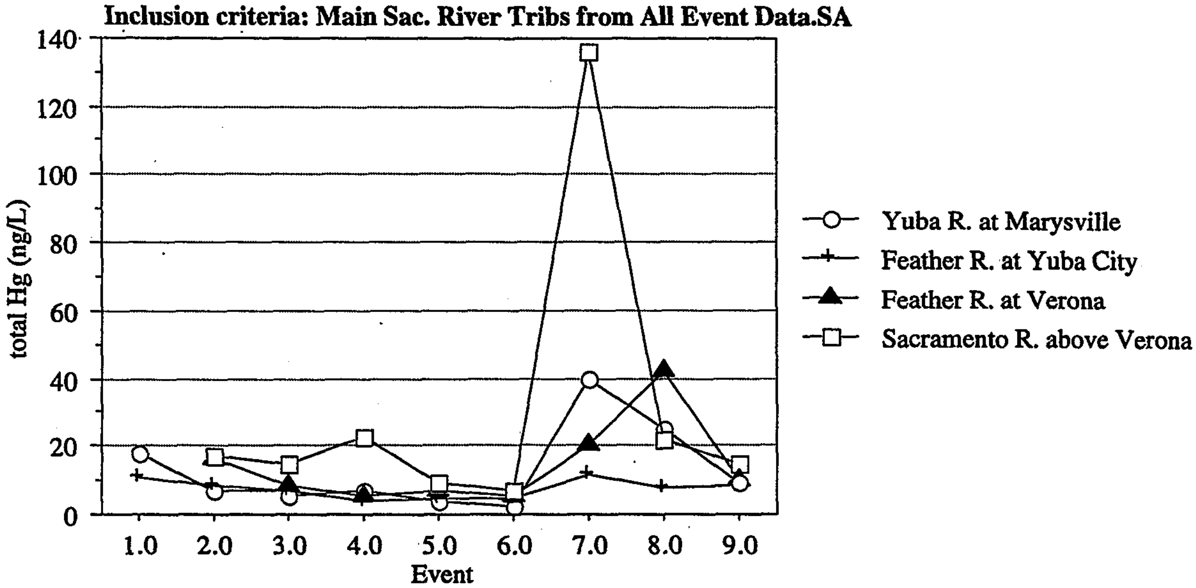
Electroconductivity (µS/cm),	Mean	Std. Dev.	Count	Min	Max	Median
Yuba River below Englebright Res.	58.6	6.40	9	44.3	66.0	60.0
Midldle and North Forks Yuba River	58.2	4.95	10	51.0	68.0	58.2
South Fork Yuba River	67.5	33.16	12	32.0	128.7	59.0
Yuba River at Marysville	63.4	9.87	11	50.0	78.9	66.2
Feather River at Yuba City	76.4	7.80	9	64.5	90.4	76.0
Feather River. above Verona	73.4	6.22	8	62.0	82.8	73.6
Sacramento R. above Verona	132.3	33.98	8	77.4	182.0	134.5

Temperature (°C),	Mean	Std. Dev.	Count	Min	Max	Median
Yuba River below Englebright Res.	10.64	1.70	10	8.18	12.90	11.12
Midldle and North Forks Yuba River	9.02	1.90	11	7.11	14.20	8.70
South Fork Yuba River	12.57	4.83	13	6.80	23.50	10.23
Yuba River at Marysville	11.54	2.12	11	8.60	14.00	12.70
Feather River at Yuba City	13.33	4.44	9	8.20	21.42	13.17
Feather River. above Verona	14.27	4.11	8	9.64	20.38	14.08
Sacramento R. above Verona	15.08	5.16	8	8.49	20.89	14.64

Dissolved Oxygen (mg/L),	Mean	Std. Dev.	Count	Min	Max	Median
Yuba River below Englebright Res.	11.44	.66	9	10.45	12.39	11.40
Midldle and North Forks Yuba River	11.79	.61	10	10.89	12.44	11.93
South Fork Yuba River	10.61	1.51	12	7.14	12.74	10.82
Yuba River at Marysville	11.15	1.01	8	9.90	12.48	10.93
Feather River at Yuba City	10.57	1.03	8	9.30	12.12	10.51
Feather River. above Verona	10.61	.95	7	9.65	12.04	10.34
Sacramento R. above Verona	9.93	1.31	7	8.10	11.88	9.48

Figure A-1.
Water Quality in Main Sacramento River Tributaries:
Total and Dissolved (0.2 μm filtered) Mercury

Line Chart
Split By: Location
Inclusion criteria: Main Sac. River Tribs from All Event Data.SA



Line Chart
Split By: Location
Inclusion criteria: Main Sac. River Tribs from All Event Data.SA

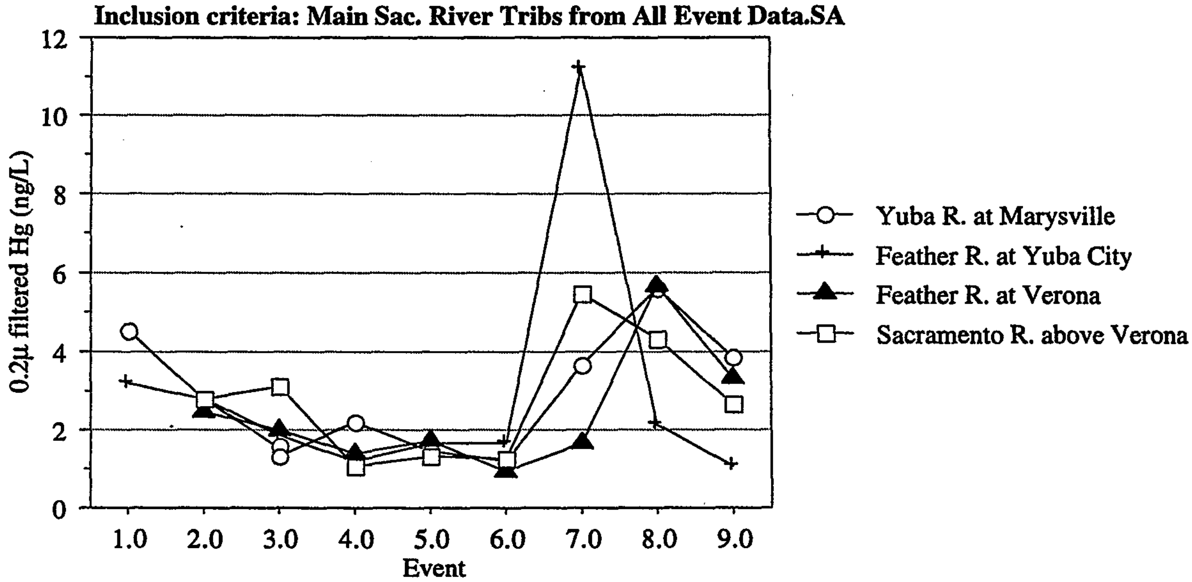
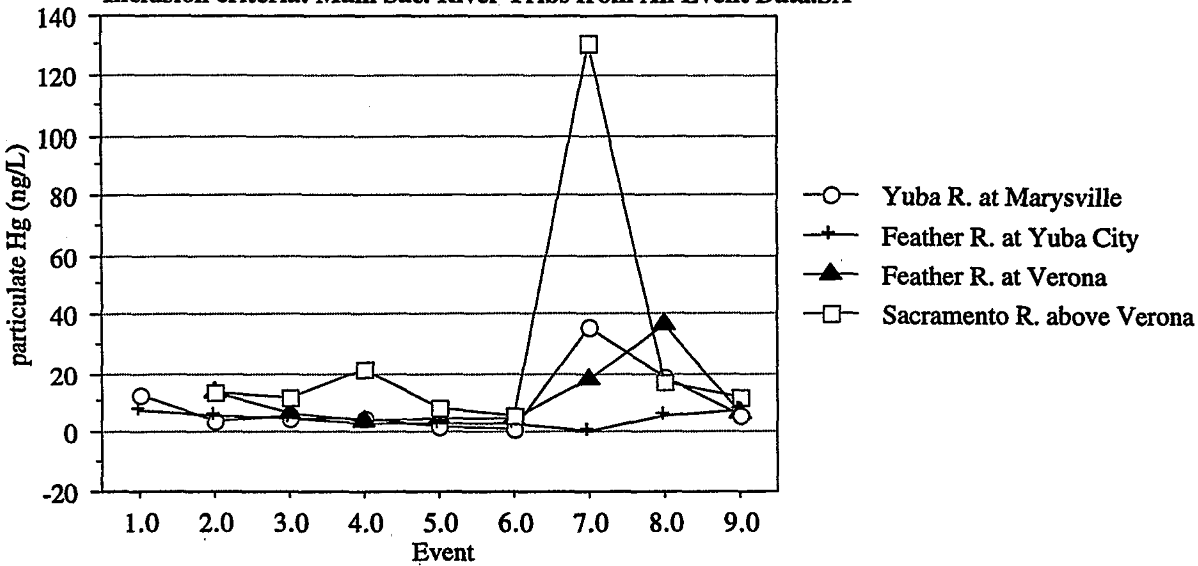


Figure A-2.
Water Quality in Main Sacramento River Tributaries:
Particulate Mercury and Total Suspended Solids (TSS)

Line Chart
Split By: Location
Inclusion criteria: Main Sac. River Tribs from All Event Data.SA



Line Chart
Split By: Location
Inclusion criteria: Main Sac. River Tribs from All Event Data.SA

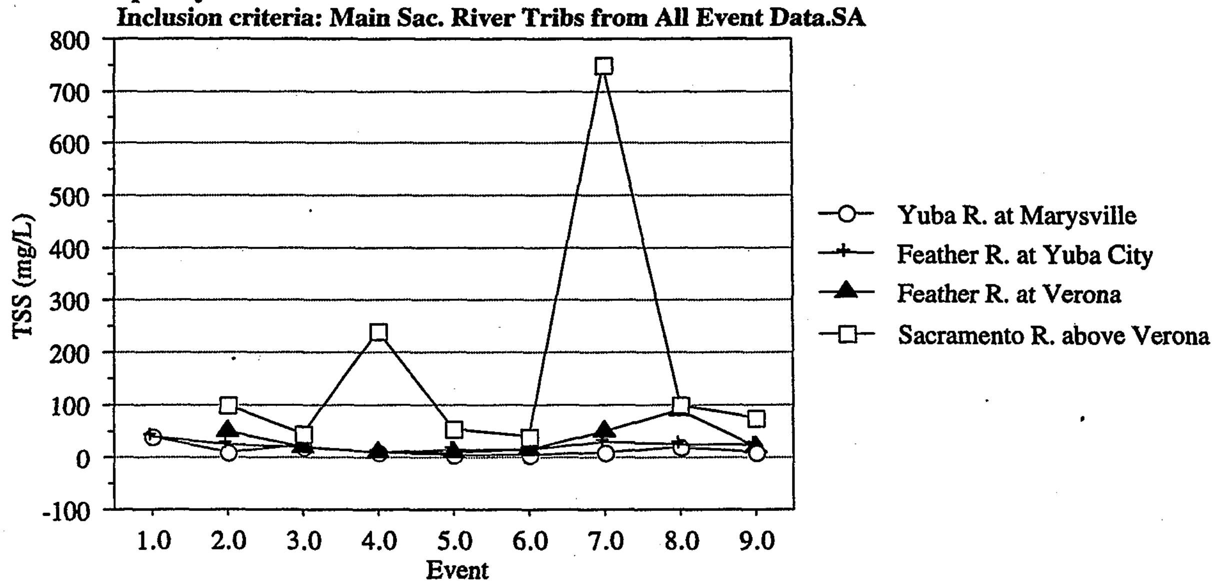
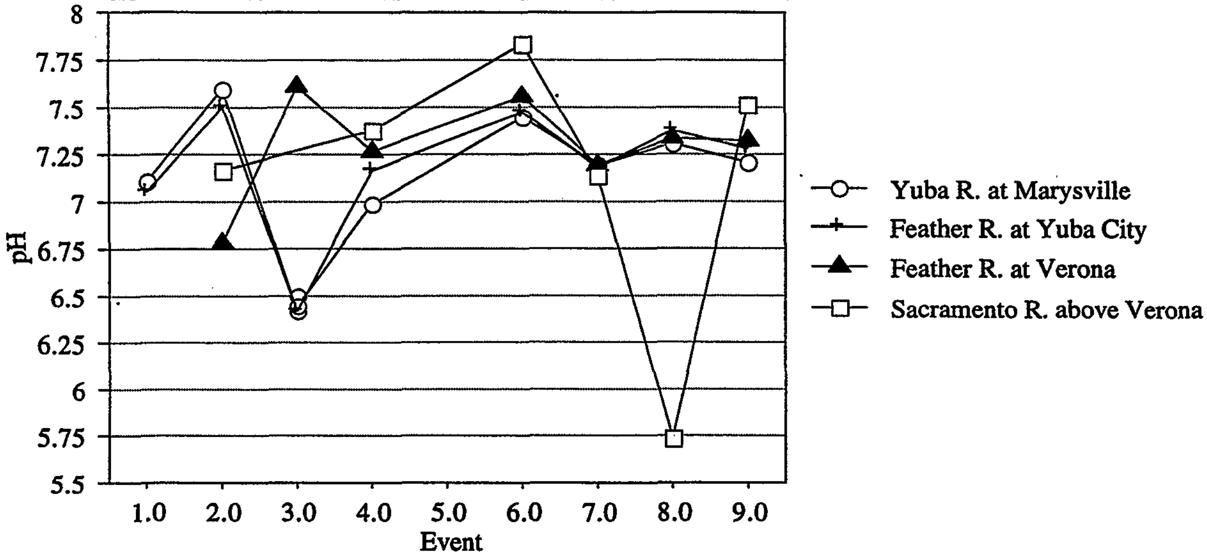


Figure A-3.
Water Quality in Main Sacramento River Tributaries:
pH and Electroconductivity (EC)

Line Chart
Split By: Location
Inclusion criteria: Main Sac. River Tribs from All Event Data.SA



Line Chart
Split By: Location
Inclusion criteria: Main Sac. River Tribs from All Event Data.SA

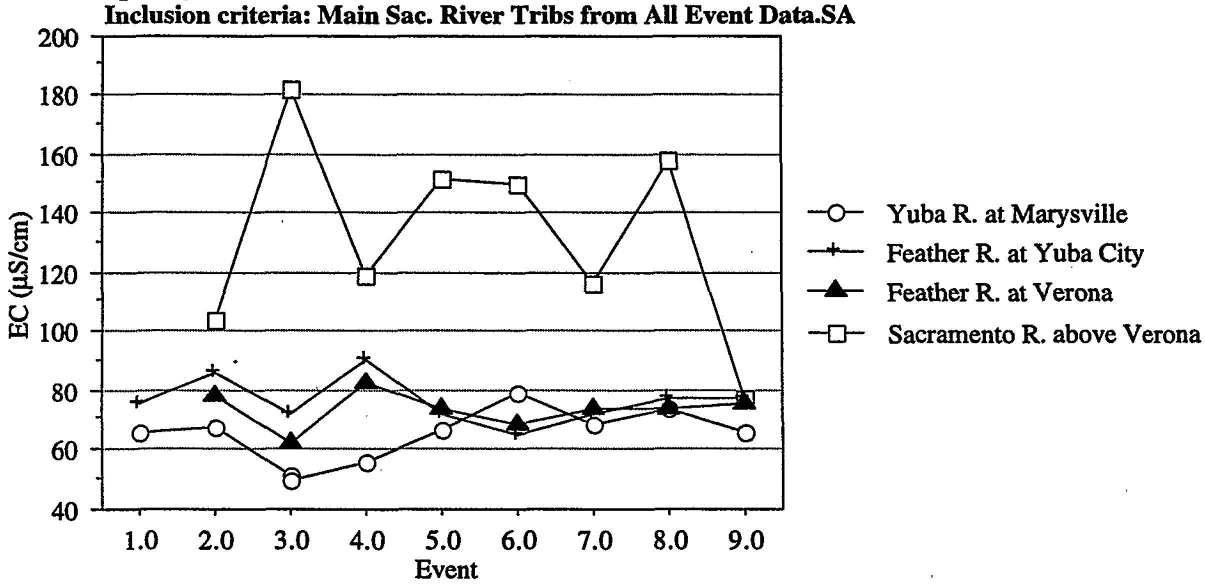
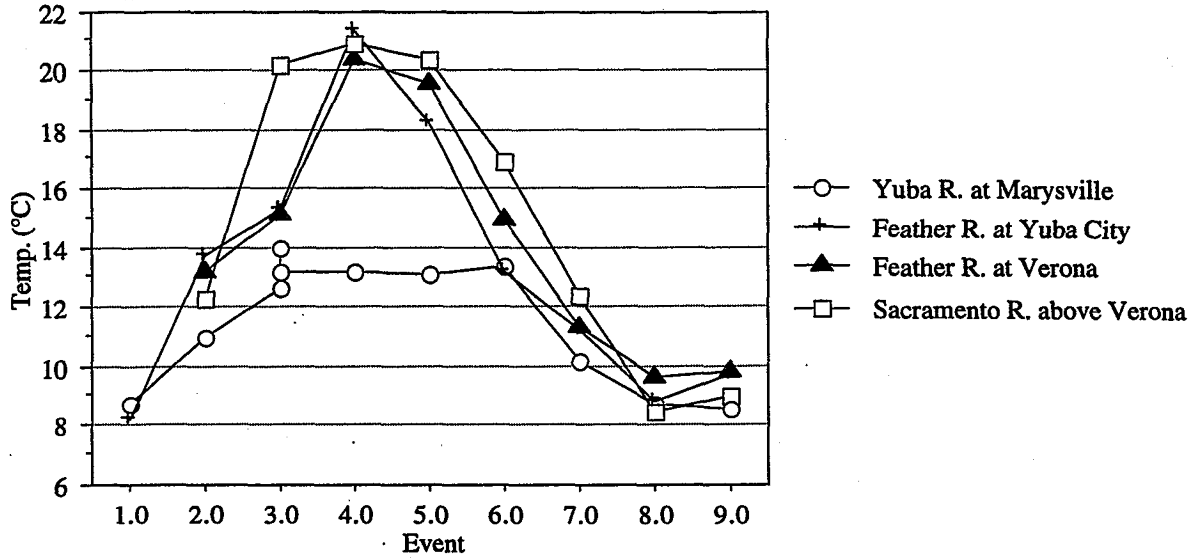


Figure A-4.
Water Quality in Main Sacramento River Tributaries: Temperature and Dissolved Oxygen (DO)

Line Chart
Split By: Location
Inclusion criteria: Main Sac. River Tribs from All Event Data.SA



Line Chart
Split By: Location
Inclusion criteria: Main Sac. River Tribs from All Event Data.SA

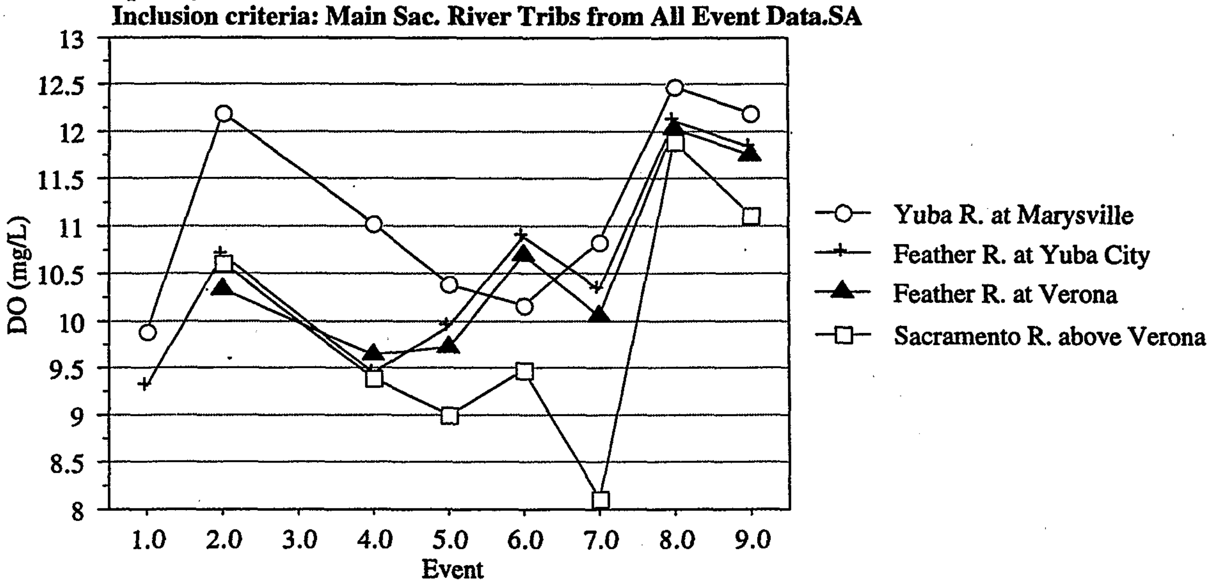
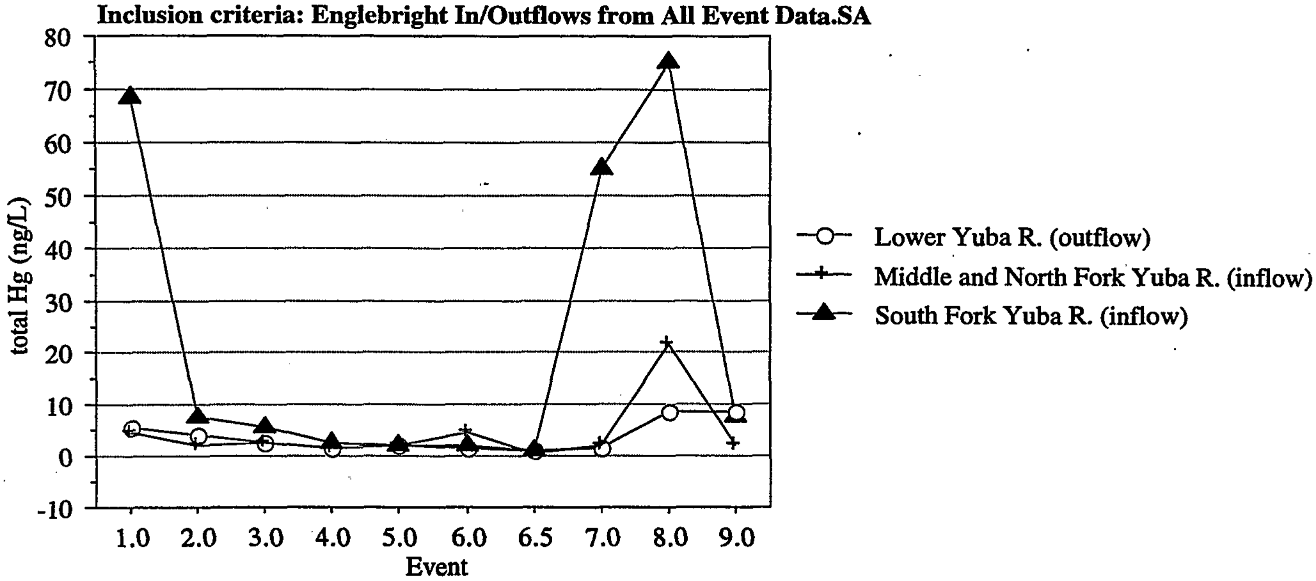


Figure A-5.
Water Quality in Englebright Reservoir Inflows and Outflows:
Total and Dissolved (0.2 μm filtered) Mercury

Line Chart
Split By: Reach
Inclusion criteria: Englebright In/Outflows from All Event Data.SA



Line Chart
Split By: Reach
Inclusion criteria: Englebright In/Outflows from All Event Data.SA

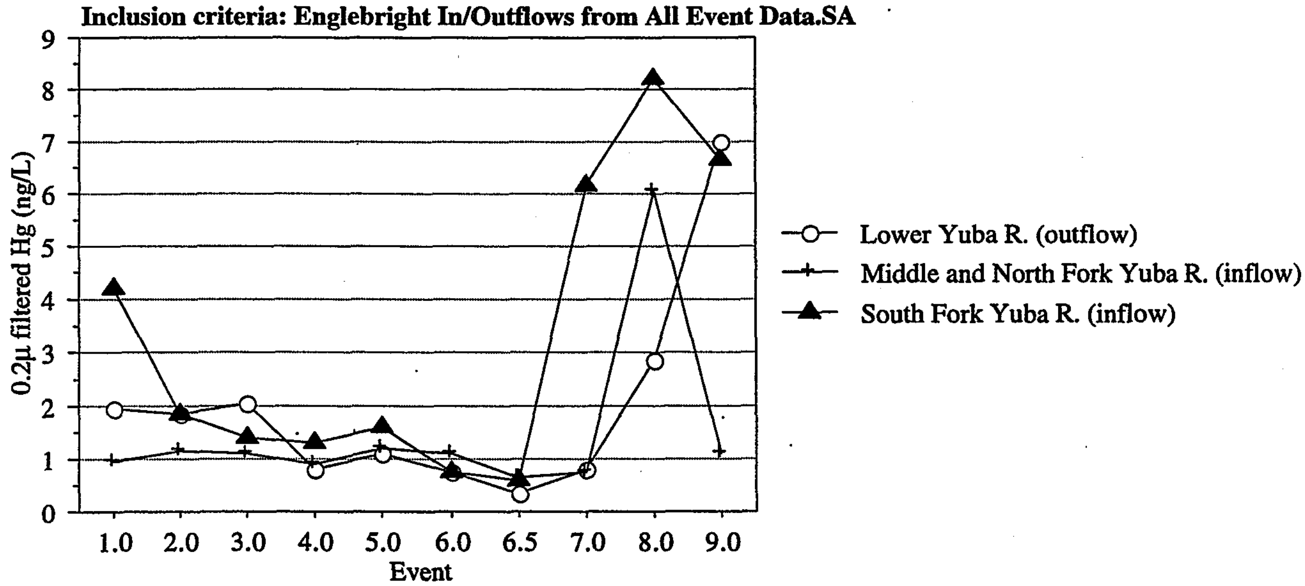
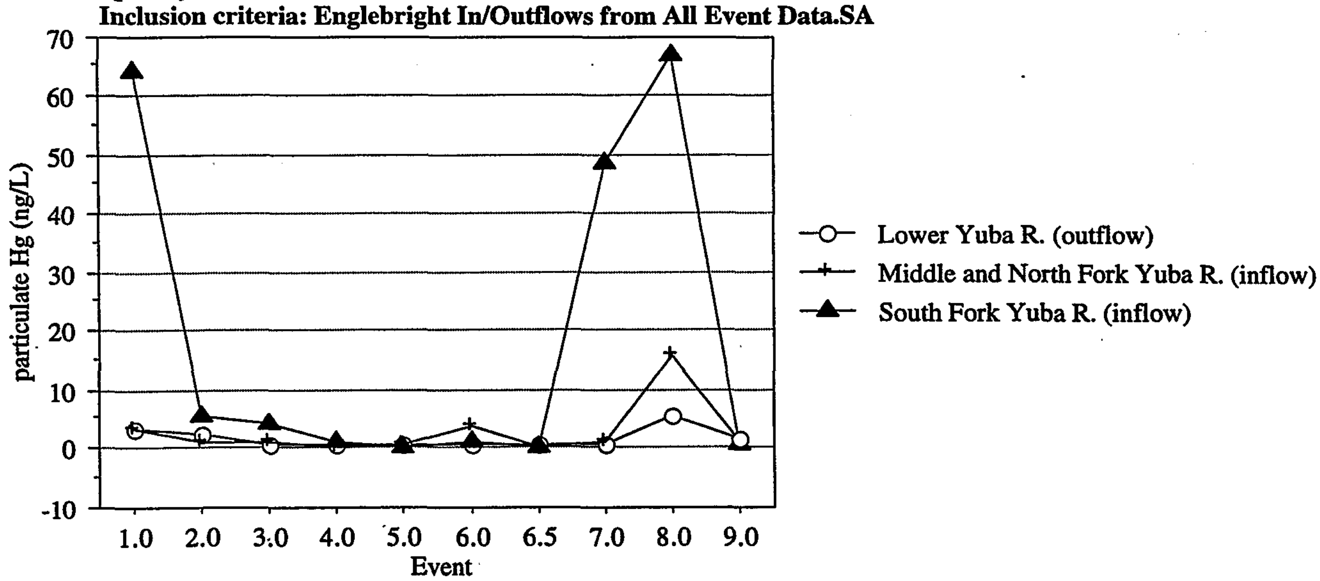


Figure A-6.
Water Quality in Englebright Reservoir Inflows and Outflows:
Particulate Mercury and Total Suspended Solids (TSS)

Line Chart
Split By: Reach
Inclusion criteria: Englebright In/Outflows from All Event Data.SA



Line Chart
Split By: Reach
Inclusion criteria: Englebright In/Outflows from All Event Data.SA

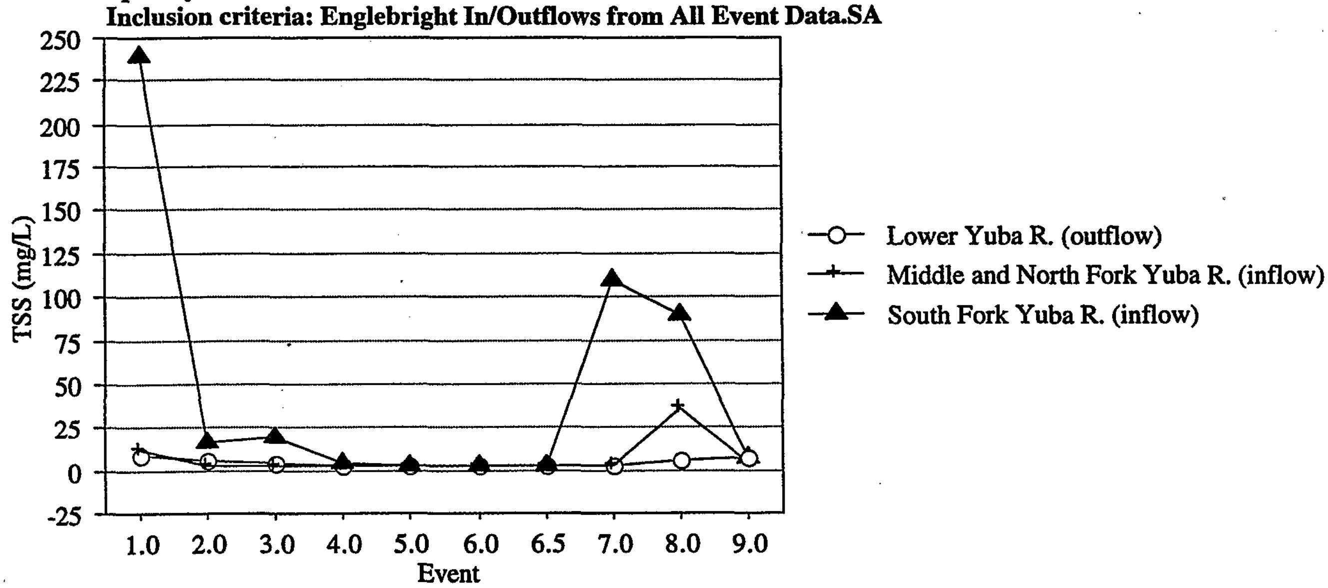


Figure A-7.
Water Quality in Englebright Reservoir Inflows and Outflows:
Total and Dissolved (0.2 µm filtered) Methylmercury

Line Chart
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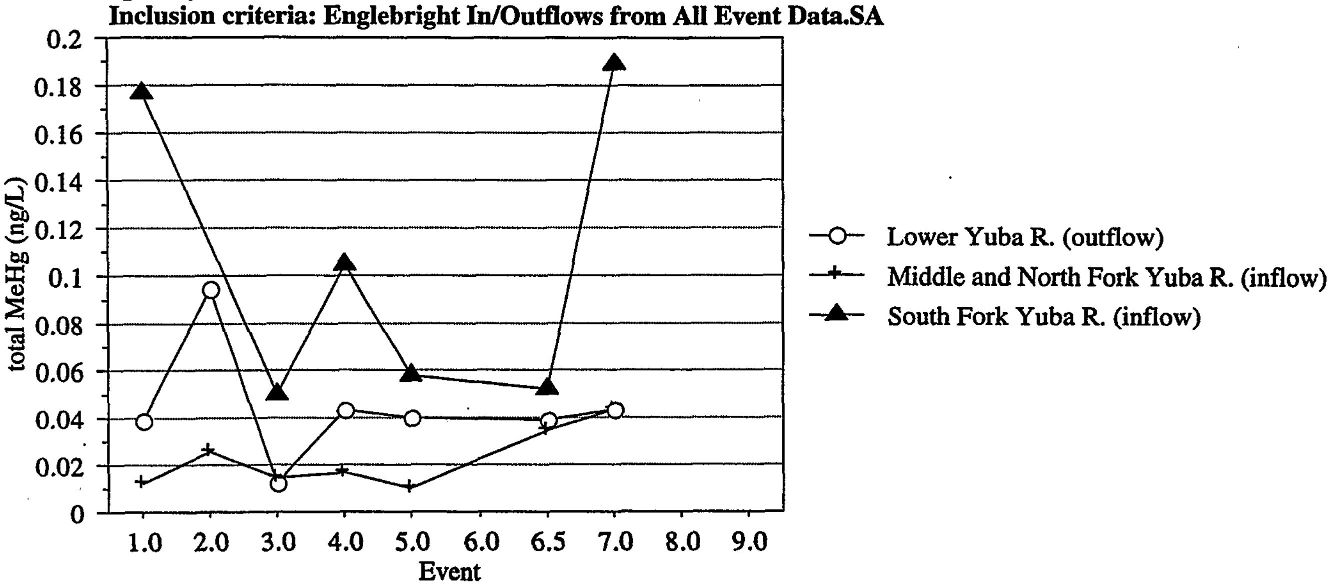

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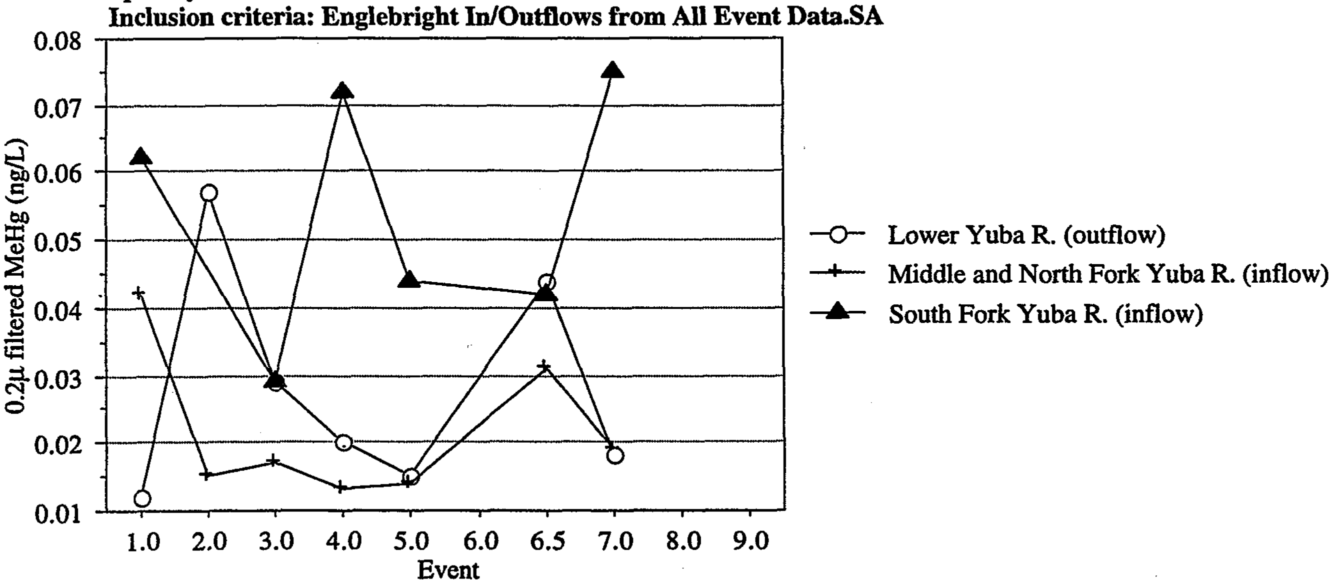

Figure A-8.
Water Quality in Englebright Reservoir Inflows and Outflows:
Particulate Methylmercury and Total Suspended Solids (TSS)

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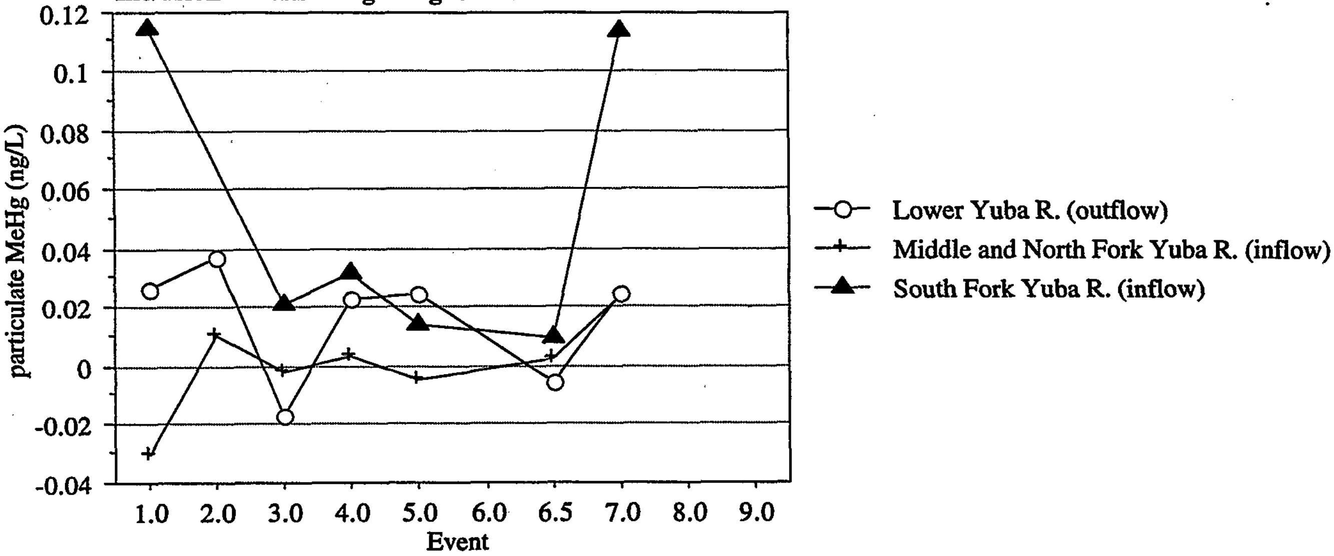

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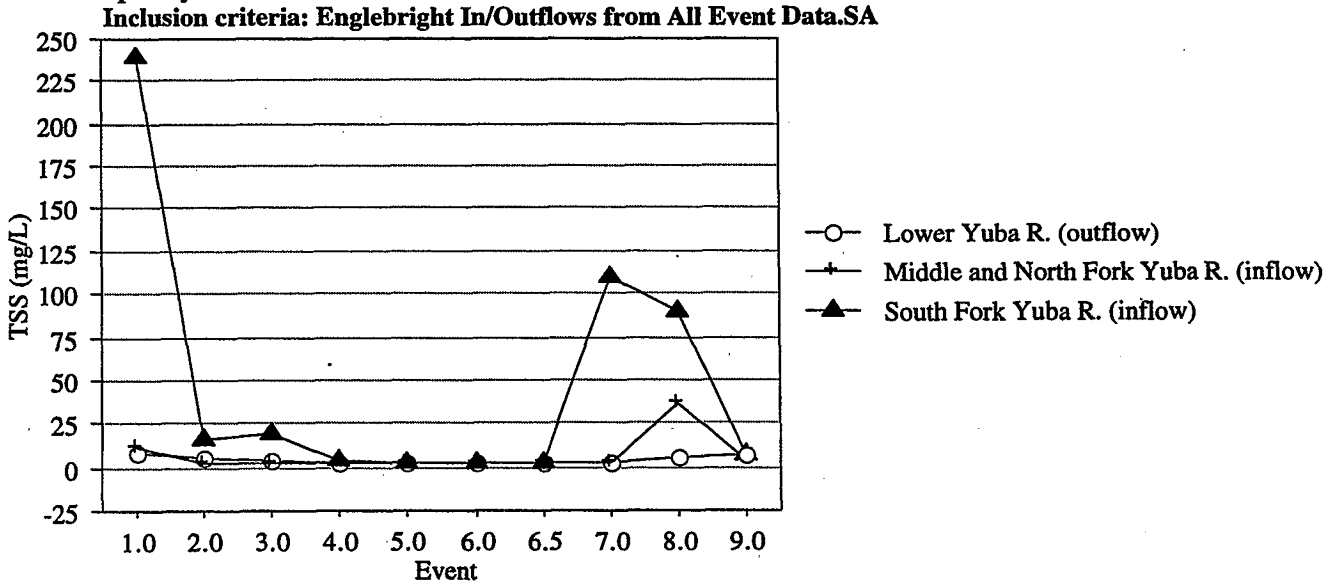
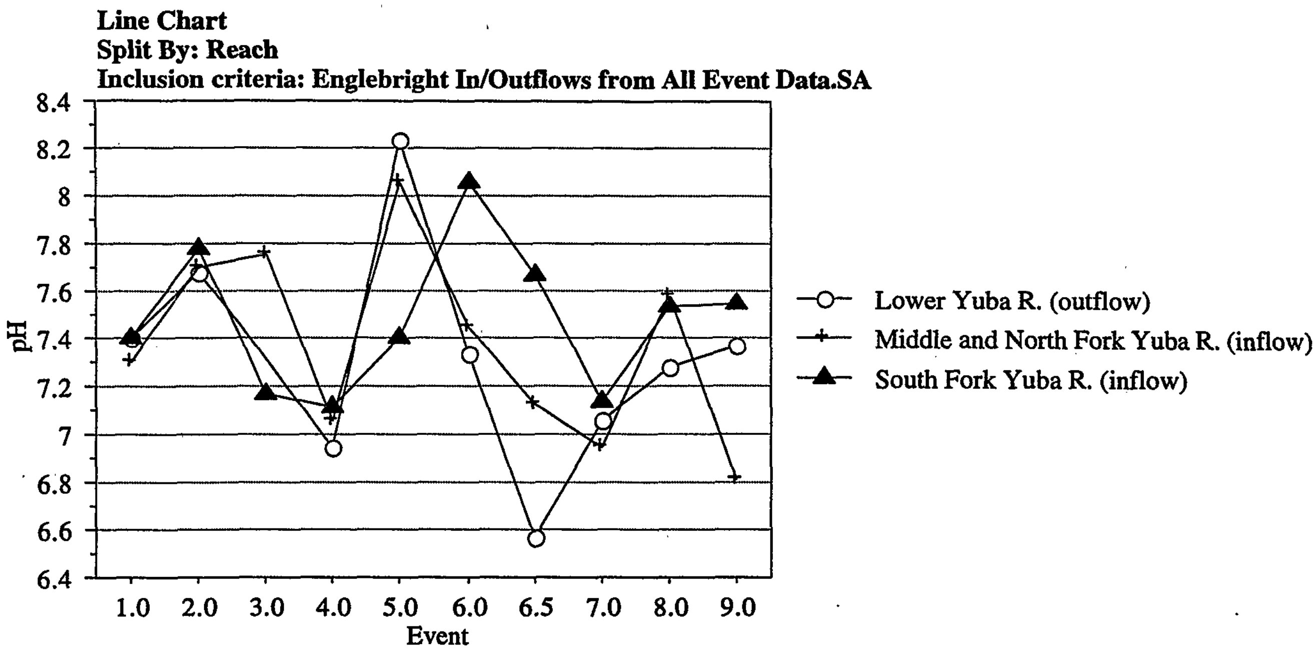


Figure A-9.
Water Quality in Englebright Reservoir Inflows and Outflows:
pH and Electroconductivity (EC)



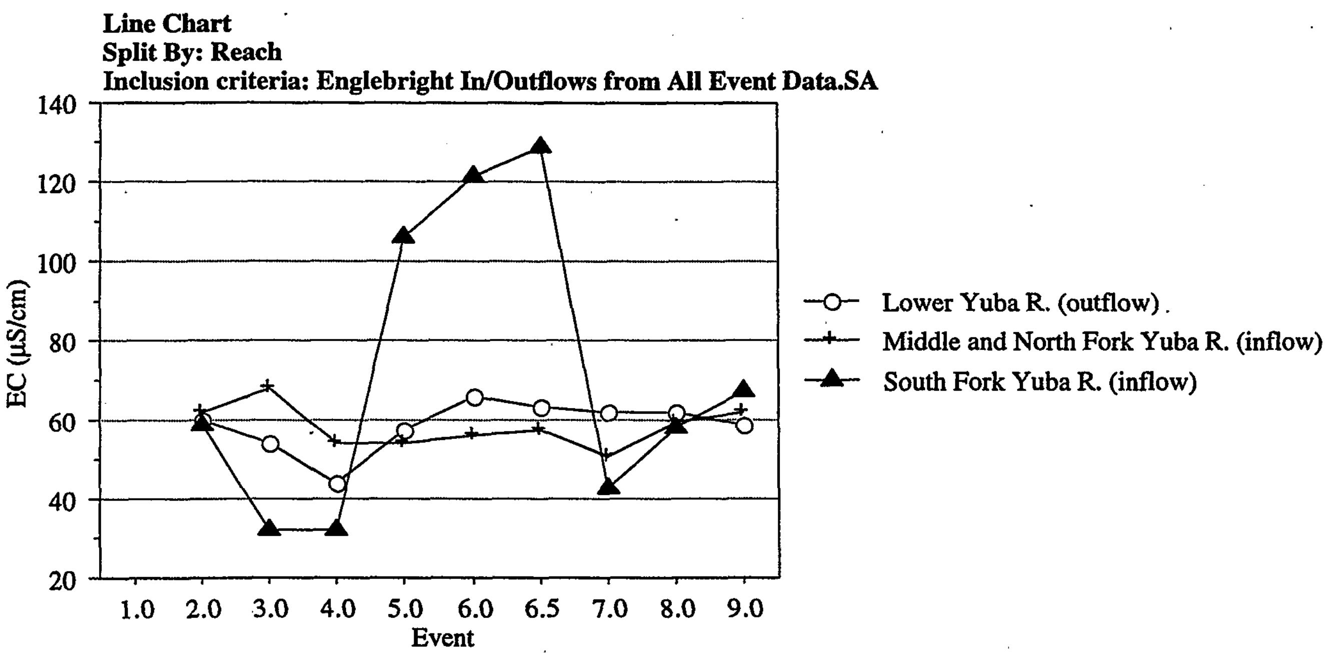


Figure A-10.
Water Quality in Englebright Reservoir Inflows and Outflows: Temperature and Dissolved Oxygen (DO)

Line Chart
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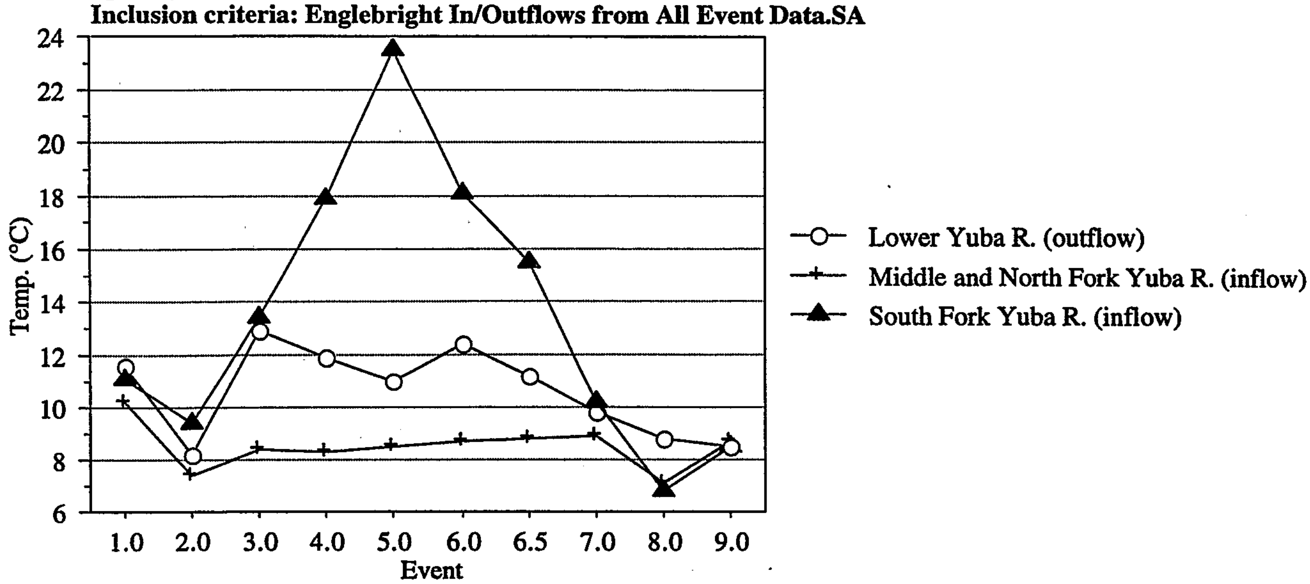
Inclusion criteria: Englebright In/Outflows from All Event Data.SA



Line Chart
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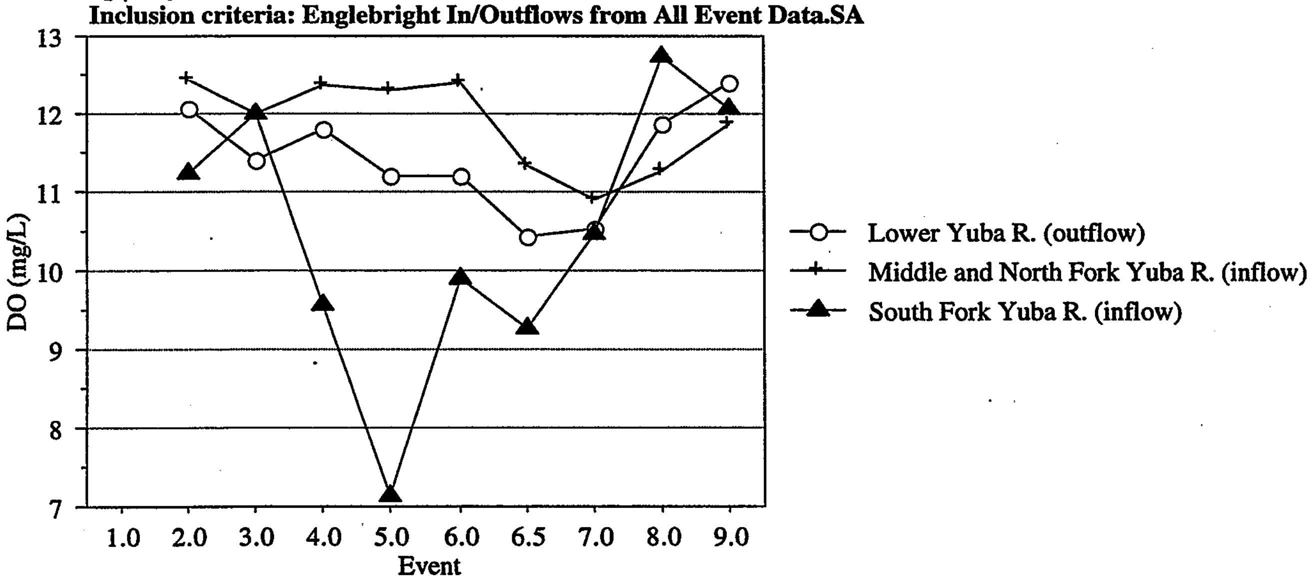
Inclusion criteria: Englebright In/Outflows from All Event Data.SA



APPENDIX B

FINAL BIOTA DATA REPORT

GOLD MINING IMPACTS ON FOOD CHAIN MERCURY IN NORTHWESTERN SIERRA NEVADA STREAMS (1997 REVISION)

By

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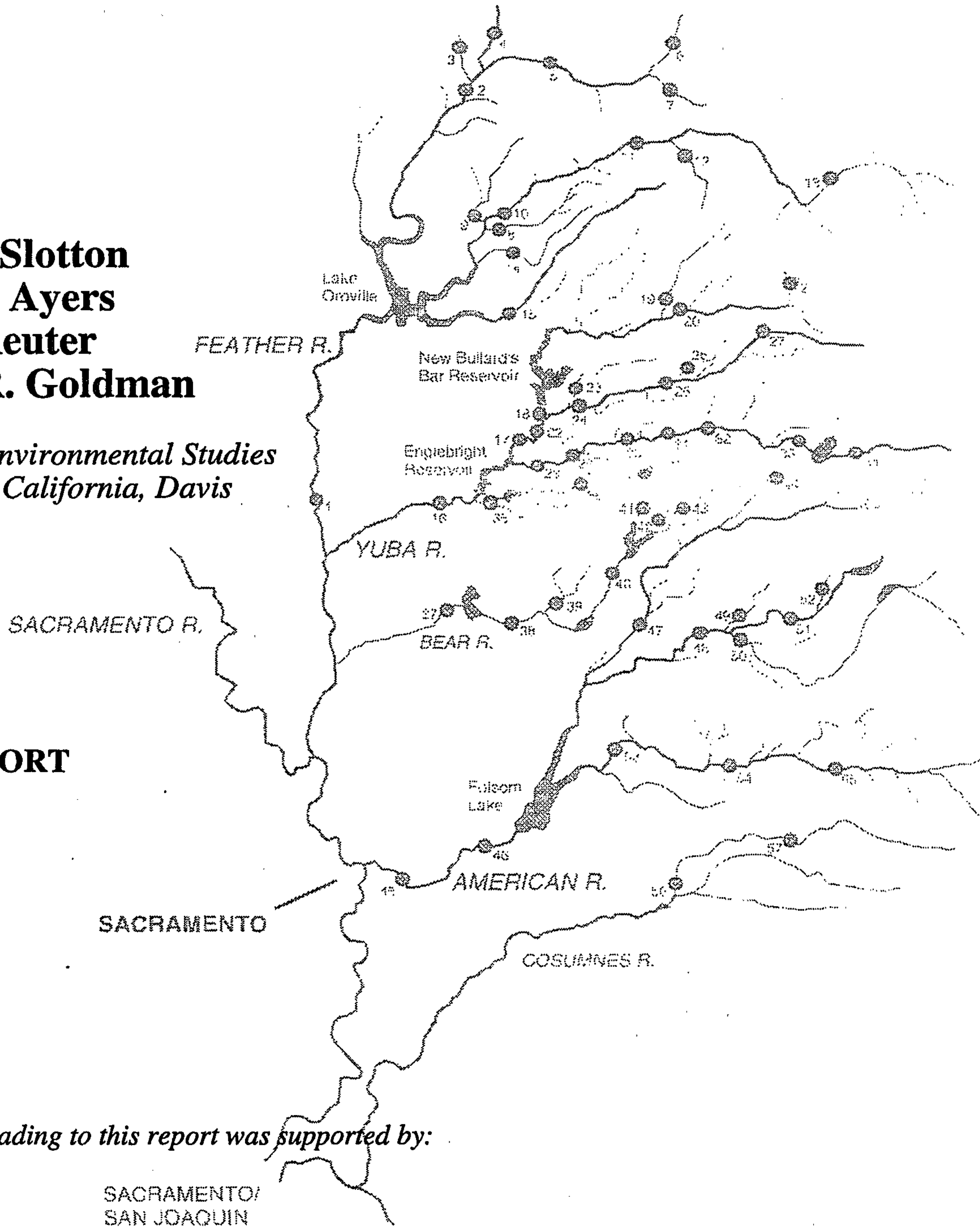


FINAL REPORT

March 1997

The research leading to this report was supported by:

The University of California Water Resources Center

and

The Sacramento Regional County Sanitation District

ABSTRACT / EXECUTIVE SUMMARY

In this research, we investigated mercury levels in aquatic invertebrates and trout within the historic gold mining region of the northwestern Sierra Nevada, in order to determine the localized biological impacts of mining-derived mercury. These organisms were used as indicators of specifically the bioavailable fraction of mercury, that portion which can enter, transfer through, and be concentrated by the food web. The biota samples were used to determine relative "hot spots" of mercury contamination and to rank the various streams and rivers as to relative bioavailable mercury levels. Trout mercury was investigated also from a health perspective, for comparison with existing mercury guidelines.

Fifty-seven sites were sampled throughout the region during the three years of this study. A clear signature of mining-derived mercury was found, with notably elevated levels in the aquatic food webs of the South and Middle forks of the Yuba River, the mid-section of the Middle Fork of the Feather River, Deer Creek, the North Fork of the Cosumnes River, and tributaries throughout the Bear River drainage. Mercury was low throughout most of the American and Feather River watersheds and in many tributaries away from the most intensively mined stretches of rivers. Elevated mercury regions did not demonstrate a point source signature. Where biotic accumulations of mercury were elevated, this elevation was generally distributed across many miles of stream or river. The elevated bioavailable mercury regions could thus be localized to specific tributaries or series of river miles, but not to highly localized "hot spot" point sources. This is consistent with the historic widespread use of mercury throughout the gold mining region and its subsequent redistribution downstream.

Mercury concentrations in trout, while variable, were found to be uniformly below existing health standards, indicating the lack of a direct health hazard within the region itself. Foothill reservoirs were found to operate as interceptors of bioavailable mercury, in addition to trapping much of the sediment-associated inorganic load. Significantly lower bioaccumulated levels were found throughout the food web below several reservoirs, as compared to upstream. Concentrations of mercury in aquatic indicator organisms increased in a predictable pattern with increasing trophic feeding level. Aquatic invertebrate samples can be used to determine relative mercury presence and bioavailability, to predict mercury levels in co-occurring trout, and to integrate localized bioavailable mercury conditions over the lifetime of the respective organisms.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ACKNOWLEDGMENTS

We are grateful to the many agency personnel who were generous with their time and conversation and who helped direct our site selection process in the early stages of the project. We also appreciate being provided access to several otherwise difficult to reach sites. In particular, we thank staff of: the Foresthill Ranger District in the American River watershed, the North Yuba Ranger Station in the Yuba River watershed, various stations in the Feather River area, the Yuba Water Agency, the University of California Agricultural Field Station at the lower Yuba River, the Central Valley Regional Water Quality Control Board, and the California Department of Fish and Game. The State Toxic Substances Monitoring Program supplied much parallel and related data and, in large part, provided the basis for this work. Special thanks go to our colleague, Dr. Michael Brett, who played an important role in the development of this project and who provided helpful suggestions throughout the data reduction and interpretation process.

INTRODUCTION: PROBLEM AND RESEARCH OBJECTIVES

Mercury pollution of aquatic systems is a major concern of researchers and regulatory agencies on both a regional and global scale. In its methylated form, mercury is readily concentrated and transferred through aquatic food chains, where it can become a significant neurological toxicant to higher trophic level consumers, including man. The primary pathway into humans is fish consumption. Much of the current mercury research is focused on the pervasive problem associated with low level atmospheric deposition of industrially-derived mercury across wide areas which have low pH and poorly buffered surface waters. In these regions, mercury can accumulate to dangerous levels in fish with even trace level inputs (e.g. the Northeast United States, Southeast Canada, Scandinavia and much of Western Europe). While the high alkalinity waters of the western U.S. render atmospheric sources of mercury relatively insignificant, California has historically been impacted by large-scale bulk contamination of mercury. This has been the result of extensive mercury mining in the Coast Range of Central California, the use of very large amounts of mercury in Sierra Nevada streams and rivers for gold mining, and the subsequent movement of mercury from both of these areas into downstream rivers and lakes, foothill reservoirs, and ultimately the Delta/Bay ecosystem. In this work, we investigated regional patterns of mercury accumulation in aquatic biota collected in the historic and current gold mining region of the northwestern Sierra Nevada. While some attention has been devoted to mercury accumulation in downstream sinks, little or no research has focused on probable upstream source regions associated with current and, primarily, historic use of mercury for gold mining. It has been estimated that over 3 million kilograms of mercury were lost into Sierra Nevada streams in the course of the California Gold Rush (CVRWQCB 1987).

Previous biological sampling efforts in these streams, as part of the State's Toxic Substances Monitoring Program (TSMP 1990, 1991, 1992), have been limited and most of this was done prior to the 1986 floods and the resurgence of small scale mining. Indeed, much of the routine sampling for the TSMP program is conducted on the lower reaches of the stem rivers and in foothill reservoirs. Mining, on the other hand, is concentrated along mid-elevation stretches of northern Sierra Nevada rivers, namely the forks of the upper Feather, Yuba, and American Rivers, the Bear River, Rubicon River, Cosumnes River, and the Mokelumne River. These rivers have been sampled sporadically by the Toxic Substances Monitoring Program (TSMP 1990, 1991, 1992). However, site selection and the species composition of the fish collected indicates that this work was generally carried out in regions well downstream of the reaches where gold mining is prevalent. We feel our data constitutes a valuable contribution to the Program's data base and its objective of identifying human health risks and major sources of toxic substances.

Small scale mining, suction dredging and panning for gold in the northwest region of the Sierra Nevada mountains has increased markedly during the last ten years. This is in part attributable to the recent series of flood runoff years in 1986, 1993, and 1995, which impacted the channel of many rivers in this region and, in the process, exposed new gold. The massive flows occurring at the time of this publication (December 1996 / January 1997) will undoubtedly continue this process. These high flows also exposed and mobilized old mercury. Additionally, current mining activity could potentially introduce additional mercury to the streams as well as disrupt formerly buried historic mercury. This project addresses the status of mercury contamination in northwestern Sierra Nevada gold mining streams, both in terms of on-site biotic mercury accumulation and as potentially ongoing sources of mercury contamination to downstream regions. The primary objectives of the project have been to:

- Determine levels of mercury in stream biota within the region most impacted by historic and current gold mining and demonstrate whether there is significant localized uptake of mercury into the stream food web in the vicinity of major historic and current mining operations.
- Produce data which will help to assess the importance of this region as an ongoing source of mercury to downstream rivers and reservoirs, and rank upstream tributaries in terms of mercury bioavailability.
- Determine whether a human or environmental health hazard exists in relation to trout mercury concentrations in the project area.
- Supplement mercury information collected from other areas of the state.

We believe that all of these objectives were achieved in this work, together with a number of other important scientific findings.

We chose mid-elevation sampling sites from among the main Sierra Nevada gold-mining rivers (Figure 1, Table 1). During the three years of the project reported here (1993-1995), we focused on the region between the Feather River watershed and the American River watershed, including the forks of the upper Feather, Yuba, Bear, and American Rivers. Special attention was given to those areas with high densities of active mining claims. These locations were determined by communication with agency and other personnel familiar with given stretches of river, and through our own reconnaissance. We soon determined that mercury distribution was very widespread throughout this region and the most effective sampling approach was to, as extensively as possible, sample throughout these rivers and their major tributaries. Where possible, samples were collected at or just below actively mined stretches of river, as well as at control sites upstream and/or along unmined stretches.

In this research, we utilized exclusively biotic samples. In-stream aquatic insect species were sampled as bioindicators of relative mercury bioavailability at each of the sites and as surrogates for fish, which were not available at many of the sites. The invertebrate mercury data also provided information on the transfer of mercury through the stream food web. Fish were of interest for their specific mercury concentrations, from a health perspective, as well as also being indicators of relative mercury availability. We chose rainbow trout as one focus of the survey because this species is the dominant vertebrate in many of these rivers, and because mercury bioaccumulation in this species represents perhaps the main vector of human exposure to mercury in this region. Other fish were sampled when available.

Sampled trout were generally representative of individuals taken by fishermen. While a range of sizes and ages were taken, the focus was on three year olds, typically 9-12 inches in length. Trout of this size class dominate angling catches, are the major contributors to in-stream reproductive success of this species, and are the group most heavily relied upon by the Department of Fish and Game in both research and policy making (Harry Rectenwald, Calif. Dept. of Fish and Game, personal communication). Stream aquatic insects were taken from a variety of trophic levels whenever possible, as described below in the methodology section.

The first two years of the work reported here were sponsored by the University of California Water Resources Center. Thirty-five individual sampling sites were studied in 1993 and 1994 and reported on in Slotton *et al.* 1995a. The Sacramento Sanitation District sponsored U.C. Davis follow-up work in 1995, sub-contracted through Larry Walker and Associates. As part of the 1995 continuation work, biota mercury was investigated at 22 additional sites, completing a comprehensive network of 55 sites throughout the Sierra Nevada drainage of the Sacramento River (plus 2 sites on the Cosumnes River of the San Joaquin drainage). The 1995 biological work was conducted in parallel with mercury mass balance and water quality studies which were performed by Larry Walker and Associates. The results of that project are presented in a separate report. The report that follows focuses specifically on the U.C. Davis biological mercury project that was conducted in the gold mining region of the nothwestern Sierra Nevada between 1993 and 1995. This report is a December 1996 revision of the original University of California Water Resources Center publication, including the additional (1995) data and new discussion as appropriate.

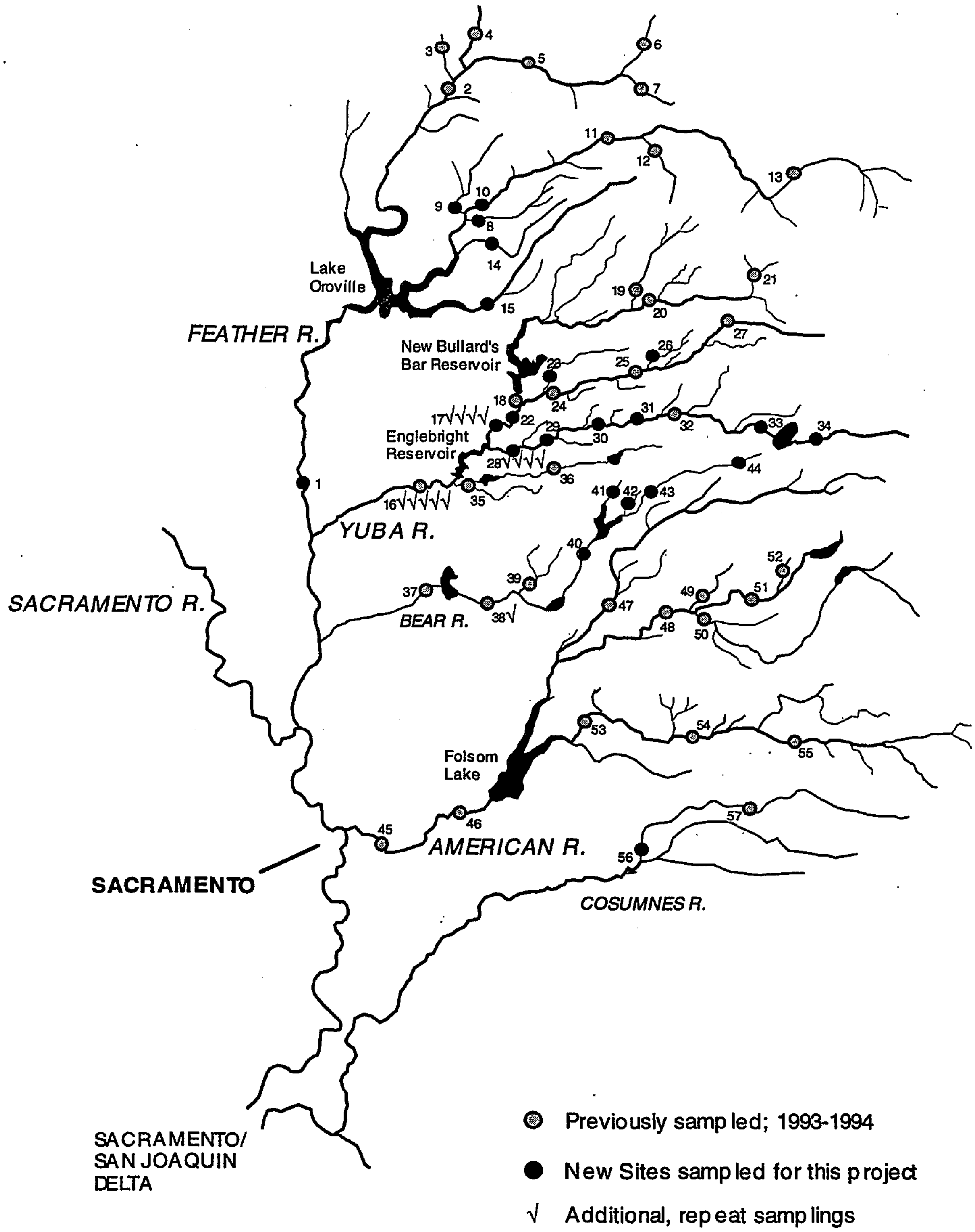


Fig. 1. U.C. Davis Northwest Sierra Nevada Biotic Sampling Sites, 1993-1995

C-035558

Table 1. U.C. Davis Sierra Nevada Gold Region Biotic Mercury Sites

FEATHER RIVER DRAINAGE

1. Lower Feather River below Lake Oroville, near Live Oak (11/17/95).
2. North Fork Feather River at Belden (10/26/94).
3. Yellow Creek (tributary to N Fk Feather R), 2 miles above confluence (6/11/94).
4. Caribou Branch of North Fork Feather River, 4 miles above confluence (10/27/94).
5. East Branch of North Fork Feather River, 10 miles above confluence with Caribou Branch (10/26/94).
6. Indian Creek, tributary to E Branch N Fk Feather River, 7 miles above confluence (9/27/94).
7. Spanish Creek, tributary to E Branch N Fk Feather River, 2 miles above confluence (9/26/94).
8. South Branch Middle Fork Feather River, at M Fk Feather River (11/21/95).
9. Little North Fork Middle Fork Feather River, at M Fk Feather River (11/21/95).
10. Middle Fork Feather River, 15 miles upstream of Lake Oroville at Milsap Bar (11/21/95).
11. Middle Fork Feather River, 1 mile below Nelson Creek (9/22/94).
12. Nelson Creek, tributary to Middle Fork Feather River, 1 mile above confluence (9/21/94).
13. Upper Middle Fork Feather River, 3 miles upstream of Clio (9/23/94).
14. Fall River, tributary to lower Middle Fork Feather River, 3 miles above confluence (11/20/95).
15. South Fork Feather River above Lake Oroville (11/20/95).

YUBA RIVER DRAINAGE

16. Lower Yuba River below Englebright Reservoir, at University of California field station (12/16/93).
    * Additional, seasonal collections in 1995: (4/24/95, 6/30/95, 8/15/95, 11/16/95, 2/16/96).
17. Combined North and Middle Forks Yuba River, just above Englebright Reservoir.
    * 1995 seasonal collection site #2: (4/24/95, 6/30/95, 8/15/95; no inverts available 11/95 and 2/96).
18. North Fork Yuba River constrained (low) flow beneath New Bullard's Bar Reservoir (3/15/94).
19. Canyon Creek, tributary to N Fk Yuba, just above confluence (11/6/93).

Table 1. (continued)

20. North Fork Yuba River, 2 miles downstream of westmost Highway 49 crossing (11/5/93).

21. Downey Creek, tributary to N Fk Yuba, at Downieville (11/2/93).

22. Middle Fork Yuba River, upstream of Colgate Powerhouse inflow of N Fk Yuba water (11/16/95).

23. Oregon Creek (Middle Fork Yuba tributary) at Middle Fork Yuba (11/9/95).

24. Middle Fork Yuba River, just upstream of Oregon Creek and Highway 49 crossing (10/21/93).

25. Middle Fork Yuba River, 1 mile upstream of Tyler Foote crossing, near Kanaka Creek. (10/19/93).

26. Kanaka Creek (Middle Fork Yuba River tributary), at Middle Fork Yuba River (11/14/94).

27. Middle Fork Yuba River, 1 mile upstream of Plumbago Road (3/24/94).

28. South Fork Yuba River at Bridgeport, just above Englebright Reservoir.
    * 1995 seasonal collection site #3: (4/24/95, 6/30/95, 8/15/95, 11/16/95, 2/16/96).

29. South Fork Yuba River at Highway 49 crossing (11/10/95).

30. South Fork Yuba River at Purdon crossing (11/10/95).

31. South Fork Yuba River at Edward's crossing (10/4/95).

32. South Fork Yuba River 1 mile downstream of Washington (11/12/93).

33. South Fork Yuba River below Lake Spaulding (10/24/95).

34. South Fork Yuba River above Lake Spaulding (10/25/95).

35. Deer Creek below Lake Wildwood, at Mooney Flat Road (12/9/94).

36. Deer Creek at Bittney Spring Road (12/9/94).

BEAR RIVER DRAINAGE

37. Bear River below Camp Far West Reservoir (12/8/94).

38. Bear River between Camp Far West Res. and Wolf Ck confluence, at Hwy 49 (12/7/94, 11/10/95).

39. Wolf Creek, tributary to Bear River, 2 miles above confluence (12/7/94).

40. Bear River below Rollins Reservoir (10/12/95).

41. Greenhorn Creek (Bear River tributary), above Rollins Reservoir (10/13/95).

Table 1. (continued)

42. Steephollow Creek (Bear River tributary), above Rollins Reservoir (10/13/95).
43. Bear River above Rollins Reservoir and flow diversion from S Fk Yuba (10/13/95).
44. Bear River headwaters near Lake Spaulding (10/24/95).

AMERICAN RIVER DRAINAGE

45. Lower American River at Howe Avenue (12/16/94).
46. Lower American River 1 mile below Lake Natoma (12/16/94).
47. North Fork American River in vicinity of Humbug Bar (11/19/93).
48. Middle Fork American River below Oxbow Reservoir (2/25/94).
49. North Fork of the Middle Fork American River, 1 mile above confluence (3/2/94).
50. Rubicon River, tributary to Middle Fork American River, just above confluence (2/1/94).
51. Middle Fork American River at "End of the World" (2/1/94).
52. Duncan Creek, tributary to Middle Fork American River, 3 miles above confluence (11/16/93).
53. South Fork American River, above Folsom Lake (12/16/94).
54. South Fork American River, below Slab Creek Reservoir (12/20/93).
55. South Fork American River, 1 mile upstream of Pacific (4/11/94).

Additional Sites Outside the Sacramento River Drainage

56. North Fork Cosumnes River above M Fk Cosumnes confluence (7/30/95)
57. North Fork Cosumnes River at Mt Aukum Road (12/20/93).

METHODOLOGY

Site Selection

Sampling sites were chosen by a variety of methods. Likely high mercury regions were determined through conversations with employees of the Forest Service, California Department of Fish and Game, regional Water Quality Control Boards, and other agencies, as well as through our own reconnaissance and conversations with miners. Additional sites were chosen upstream and downstream of intensively mined stretches. Additional major tributaries were sampled as possible. Tributaries were sampled for trout ≥ 1 mile upstream of their confluences with main rivers, in order to minimize the importance of migration from downstream and other drainages. Stream invertebrates could be effectively sampled closer to a downstream confluence while remaining representative of the given tributary.

Collection Techniques

Stream invertebrates were taken from riffle habitat at each of the sites, i.e. from rapids or cobble bottomed stretches with maximal flow, where aquatic insects tend to be most concentrated among the rock interstices. Felt-soled boots were used to permit effective movement in this habitat. Neoprene waders were used when water temperatures were below ~12 °C. Stream invertebrates were collected primarily with the use of a kick screen. A 1.5 mm mesh size was used, trapping invertebrates thicker than this in cross section. One researcher spread and positioned the screen perpendicular to the flow, bracing the side dowels against the bottom, while the other researcher overturned boulders and cobble directly upstream of the screen. These rocks were hand scrubbed into the flow, dislodging any clinging biota. Following the removal of the larger rocks to the side of the stretch, the underlying cobble/pebble/gravel substrate was disrupted by shuffling the boots repeatedly. Invertebrates were washed into the screen by the current. The screen was then lifted out of the current and taken to the shore, where teflon coated forceps were used to pick macro-invertebrates from the screen into jars with teflon-lined caps. This process was repeated until a sufficient sample size of each taxon of interest was accumulated to permit future analysis for mercury. Whenever possible, we attempted to collect consistent samples from the following four invertebrate trophic levels: herbivores, drift feeders, small-item predators, and top insect predators. When present, we took Pteronarcyid stonefly nymphs or a variety of mayfly nymphs for the herbivore trophic level and Hydropsychid caddisfly nymphs for the drift feeding group. Medium to large Perlid stoneflies (either *Callineuria* or *Hesperoperla*) were taken wherever possible to represent the small-item predator insects, while hellgrammites (*Corydalus*) were the preferred top predator stream insect.

C-035562

Several fish collection techniques were investigated initially, including gill netting, electroshocking, and angling. We determined that angling was the most effective method for taking a cross section of trout sizes from clear, fast moving Sierra foothill rivers and streams. To guard against potentially taking seasonal migrant fish from downstream reservoirs, fish sampling was largely confined to the months of August through December. Stocked individuals were rarely taken and were easily differentiated from native fish by their characteristic fused and bent fin rays. We sampled exclusively native fish for mercury content, with the emphasis on rainbow trout. The attempt was made to collect trout across a range of sizes and ages at each site, permitting the construction of site-specific fish size vs mercury regressions. These relationships were used to normalize trout mercury content at each site to a standard, inter-comparable size of trout. We chose a standard size of 250 g for normalization. This size was typical of 2-3 year old, 9-12 inch long trout which represent the majority of "keeper" fish taken by the angling public. Fish were weighed and measured in the field. At sites where stomach contents were assessed, this was also done in the field. Stomach contents were obtained with a stainless steel scalpel and were removed to an acid-cleaned jar with teflon-lined cap. Items were identified and percent volumes assessed, following standard fisheries sampling protocol.

Sample Preparatory Techniques

Stream insects were analyzed for mercury in homogenized composite samples of multiple whole individuals. Typically, ≥ 10 individuals were composited for each of the trophic levels through small-item predators (stoneflies), and 2-5 individuals of the top predator insect group such as hellgrammites, based on availability. Samples were pooled by taxa into separate jars. The insects were maintained live on ice. Within 24 hours of collection, the contents of each jar were carefully cleaned and sorted. This was accomplished by resuspending the jar contents in a tray of clean water and, with teflon-coated forceps, individually rinsing and shaking each individual insect in the clean water to remove any extraneous material. Insects were keyed to at least the family level, using a variety of aquatic insect texts and manuals (McCafferty 1981, Merrit and Cummins 1984, Pennak 1978, Thorp and Covich 1991). Trophic feeding category of organisms was determined based on the recommendations of Merrit and Cummins (1984). In uncertain cases, the magnified examination of mouthparts was used to help make this determination. Cleaned insects were placed in well rinsed jars and frozen. At the onset of sample analysis, the jar contents were dried at 50-60 °C for 24 hours and then ground with teflon coated instruments or glass mortar and pestle to a homogeneous powder. The resulting powder was dried a second time to constant weight before analytical sub-samples were taken for digestion. All aquatic insect mercury analytical work was performed with dry powdered sample, both to ensure homogeneity of sample and to enhance mercury detection capacity. Percent moisture was determined on homogenized wet samples from several replicates of each major group, to permit the conversion between wet and dry concentrations.

In contrast to the dry, composite sample insect work, fish mercury was analyzed primarily in muscle tissue on a fresh (wet) weight basis, in accordance with standard practices which focus on the potential health risks of consuming mercury in filet meat (TSMP 1990). Muscle samples were taken from fresh fish at streamside. Fish muscle was sampled from the dorso-lateral (shoulder) region utilized by the California Department of Fish and Game. For each individual fish, the skin over the region was pulled back before the sample was taken with a stainless steel scalpel. Samples of approximately 0.2 g were rolled lightly over a laboratory tissue paper to remove extraneous surface moisture and then carefully placed into pre-weighed, acid-washed digestion tubes with teflon-lined caps. The precise weight of each muscle sample was later determined by re-weighing the digestion tubes with samples, together with empty "blank" tubes, on a balance accurate to 0.001 g. This direct sub-sampling technique reflects fresh weight muscle (filet) mercury concentrations, without introducing potential sources of error associated with homogenization techniques. We have found mercury concentration to be extremely uniform throughout the dorso-lateral region of muscle (Slotton 1991). Thus, direct sub-sampling accurately reflects overall muscle mercury concentration. For cases where liver mercury was also measured, identical procedures were followed. Wet/dry conversions were calculated for trout fillet tissue by determining percent moisture from 10 fillet samples from different fish. These were very similar and the mean value (78.2% ± 1.9%) was used to convert analyzed fresh weight parts per million mercury to a dry weight basis, for direct comparison with the invertebrate dry weight values.

Analytical Methodology

Mercury analytical methodology followed the protocols developed at U.C. Davis (Slotton 1991) and summarized in Slotton *et al.* (1995b). The method combines features of a number of previous techniques, and is notable for allowing excellent reproducibility, low detection levels, high numbers of samples per batch and thus room for high numbers of QA/QC samples, and the ability to re-analyze digests.

The method can be summarized as follows: digestion is performed in teflon-capped pyrex test tubes in a two stage process. Environmental samples are broken down in a 2:1 mixture of concentrated sulfuric acid to concentrated nitric acid, the digest mixture found to be most effective in a comparative study (Sadiq and Zaidi 1983). This first stage utilizes a temperature of 90-100 °C and pressure (sealed tubes) for 1.5 hrs, resulting in clear solutions. In the second stage, also 1.5

hrs, potassium permanganate is added for additional oxidation and digest stabilization. This portion of the digest procedure is performed at 80-95 °C with the tubes refluxing, uncapped. The resulting digests can be diluted or not, depending on the mercury concentrations and required level of detection, and are stable indefinitely, both before and following detection. Detection utilizes typical cold vapor atomic absorption techniques with a mercury lamp of 253.7 nm wavelength. The method differs from standard flow-through systems which reduce the entire digest in a one-time detection. A long path length, minimum volume gas cuvette and holder have been manufactured for positioning in the beam path and a specialized injection port allows direct introduction of reduced mercury in vapor. Reduction of digest mercury is performed inside a 12 cc calibrated syringe on a 2.0 cc aliquot of digest together with 2.0 cc of stannous chloride/hydroxylamine sulfate/sodium chloride reductant. A 6.00 cc airspace is utilized for partitioning of the volatile reduced mercury within the syringe and, after partitioning is complete, this airspace is injected directly into the low volume cuvette mounted in the beam path for detection. The amount of digest and, thus, proportion of sample detected is accurately determined through difference, with the digest tubes weighed to $\pm$ 0.001 g both before and immediately after removal of the analytical aliquot. Weight of total digest is initially determined by weighing the empty tube and then the full tube of digest. Level of detection was approximately 0.01 mg kg^{-1} (ppm).

QA/QC was quite extensive, with approximately 16 of the 40 tubes in each run dedicated to this purpose. QA/QC samples in each run included a set of 8 aqueous mercury standards, a minimum of 3 certified reference material samples in an appropriate matrix, and duplicate and spike recovery samples each at a ratio of approximately 10%. QA/QC samples passed through all phases of the digest and were treated identically to analytical samples. Replication was typically $\leq$ 5% difference between duplicates, recoveries of certified reference materials were uniformly within 20% of certified values, spike recoveries were within 20% of predicted concentrations, and standard curves generally had R^2 values in excess of 0.98.

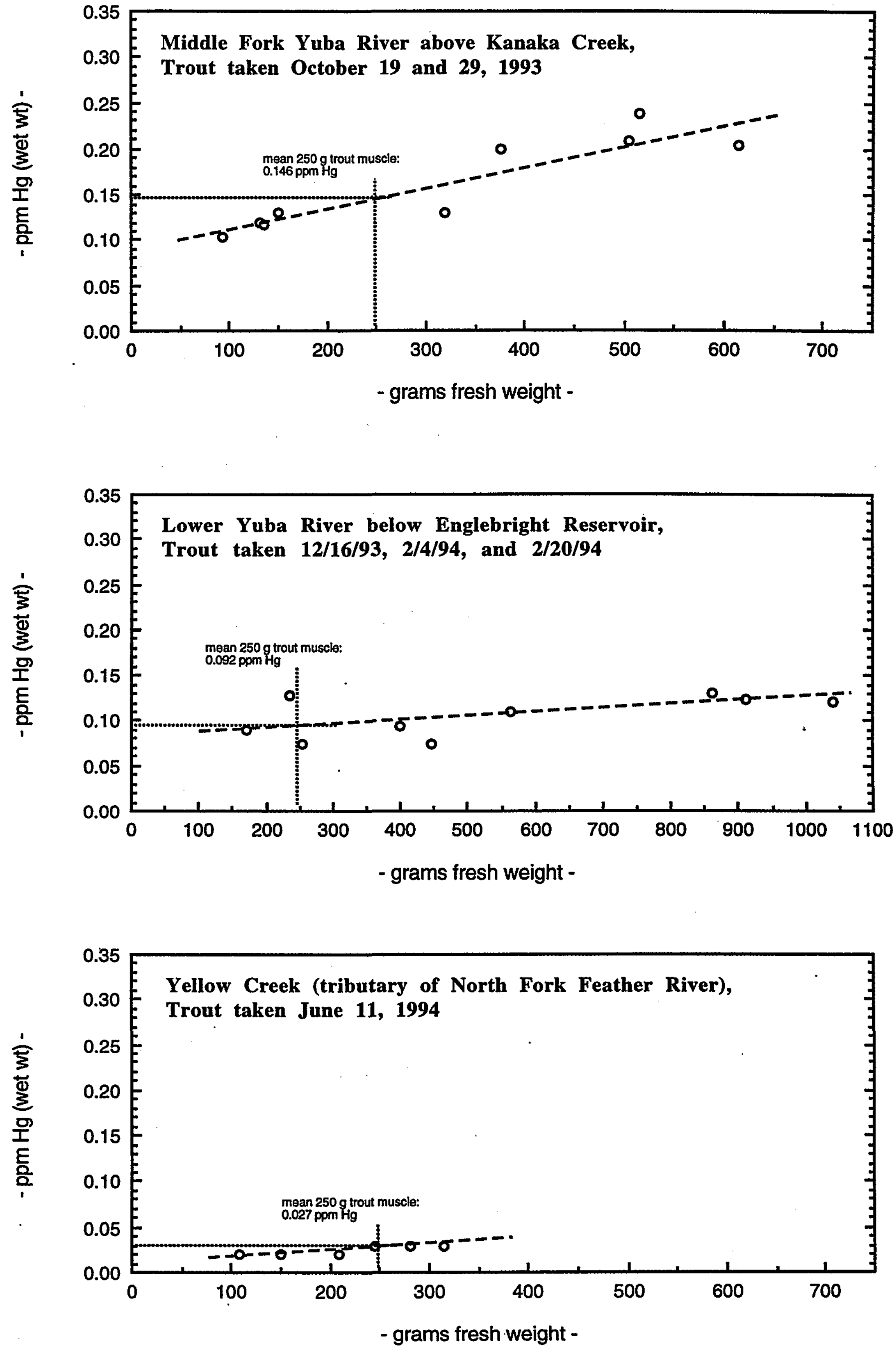
Data Reduction

In order to reduce the fish muscle mercury concentration data to a single, inter-comparable number for each site, we developed trout size vs mercury concentration curves for the fish taken at each location. Data for fish weights and corresponding mercury concentrations were plotted for each sample set. Based on a visual line of best fit, a graphic relationship between trout size and mercury concentration was estimated for each site. This approach was taken for the following reasons: (1) obvious outlier individuals could be omitted when they were clearly of different origin than the rest of the fish in a set, typically due to recent migration from an adjoining stream with different mercury bioavailability, (2) fish size vs mercury concentration relations often follow a curvilinear rather than straight line function, and (3) standard polynomial function curve fitting routines tend to wrap the upper portion of these mercury curves, unnaturally, back down toward zero, rather than following the asymptotic, steadily increasing function typical in actual fish vs mercury relations. However, a straight line could generally be fitted to the trout data of most sample sets, within the range of sizes utilized. Examples of this normalization approach are presented in Fig. 2. Map figures for trout represent normalized 250 g rainbow trout filet muscle mercury concentrations. Only samples with sufficient individuals to derive a size:mercury relationship are displayed in the map figures (21 of 24 sites where trout were taken).

Among the invertebrate samples, some of the trophic levels were well represented by a single genus throughout the majority of sampling sites, while others were represented by different members of the trophic level at different locations. While mercury concentrations for all of the individual samples are presented in the data tables, the summary map figures utilize averaging techniques in several circumstances. In the herbivore trophic level, a distinction is made between consumers of allochthonous (terrestrially derived) vegetation ("shredders") and forms which graze autochthonous, within-stream algae and aquatic plants. The shredder sub-group was dominated by samples of Pteronarcyid stoneflies. Where other shredder groups were present rather than Pteronarcyids, the average mercury level among them is plotted. Grazers of within-stream vegetation are similarly averaged. For plots which utilize only a single value for "herbivores", the average of all shredder and grazer types is used for each site. The drift feeding omnivore trophic level is represented exclusively by Hydropsychid caddisfly larvae, which were widely represented among the sampling sites (44 of the 57 sites). The first order (small item) predator trophic level is represented by Perlid stoneflies at all but 4 of the 50 stations where first order predators were taken. At these 4 stations, the average of all available first order predator samples is used. The second order (large item) predator trophic level is represented most consistently, but not overwhelmingly, by Corydalid hellgrammites, which occurred at 24 of the 33 stations where second order predators were taken. In the second order predator figure, Corydalid hellgrammite mercury is plotted alone in addition to average values for all second order predators. For plots which utilize only a single value for "second order predators", the average of all second order predator types at each site is used.

In order to reduce the often voluminous and varied trophic mercury data to a single, inter-comparable value for each site, tissue concentrations were normalized to an intermediate trophic level for each sampling site. The selection of the specific intermediate trophic level for normalization was arbitrary and does not bias comparisons between sites. The data were normalized by trophic level for each site based on an ANCOVA model of the of tissue mercury concentration vs. relative trophic level and site factors. Additional manipulation of data consisted

Fig. 2. Examples of Fish Size vs Mercury Concentration Normalization



of adding back the model residuals to the trophic level-normalized data for each site. This allowed estimation and expression of the variability (standard deviation, confidence limits) of the trophic level-normalized estimates for each site. The average trophic level-normalized mercury concentration for each site (or drainage) was used as one of several tools in comparing relative biological accumulation of mercury between sites.

RESULTS

In the three years of this study, we were able to sample aquatic biota at a total of 57 different stream and river sites throughout the Sierra Nevada foothill gold region (Figure 1, Table 1). Of the 57 sites, all but the two Cosumnes River sites were within the Sierra Nevada watershed of the Sacramento River. Sampling was generally constrained to the months of September through December for a variety of reasons, including (1) prohibitively high flow in late winter through early summer and (2) frequently low invertebrate biomass at other times of year. In 1993, we focused our sampling efforts on tributaries of the Yuba and American River watersheds, while in the second year of the project we worked mainly in the Feather River, Bear River, and Deer Creek drainages. The third year of the project concentrated on more intensive sampling of higher mercury drainages identified previously. In Table 2, biota mercury data for all sites are displayed both numerically and graphically, on a dry weight basis. Fish data for individual trout are presented in Table 3. The biotic mercury data are also displayed on a regional map, with graphic representations of mercury levels in all main trophic levels superimposed in Figure 3 and the approximated normalized mercury values for the 57 sites shown in Figure 4. Mercury trends within individual trophic categories are displayed in Figures 5-10.

Trout

Trout were sampled in sufficient numbers for statistical analysis at 21 of the 24 stream sites where fish were taken, with a total of 134 fish collected and analyzed for filet muscle mercury. This included 120 native rainbow trout, 11 small brown trout, 1 large brown trout, and 2 mid-sized squawfish. Data for individual fish are presented in Table 3 and are displayed on a regional basis in Figures 9 (dry weight ppm Hg) and 10 (wet weight ppm Hg). On a wet weight (fresh) basis, normalized filet muscle mercury concentrations in 250 g trout varied between 0.03 mg kg^{-1} (ppm) and 0.21 mg kg^{-1}. The normalized values represent the synthesis of data from 4-13 fish from each site. Trout from all sites demonstrated a generally positive size vs mercury concentration relationship, with largest fish typically having the highest concentrations. Highest trout mercury was found at sites along the Middle and South Forks of the Yuba River, and the mid

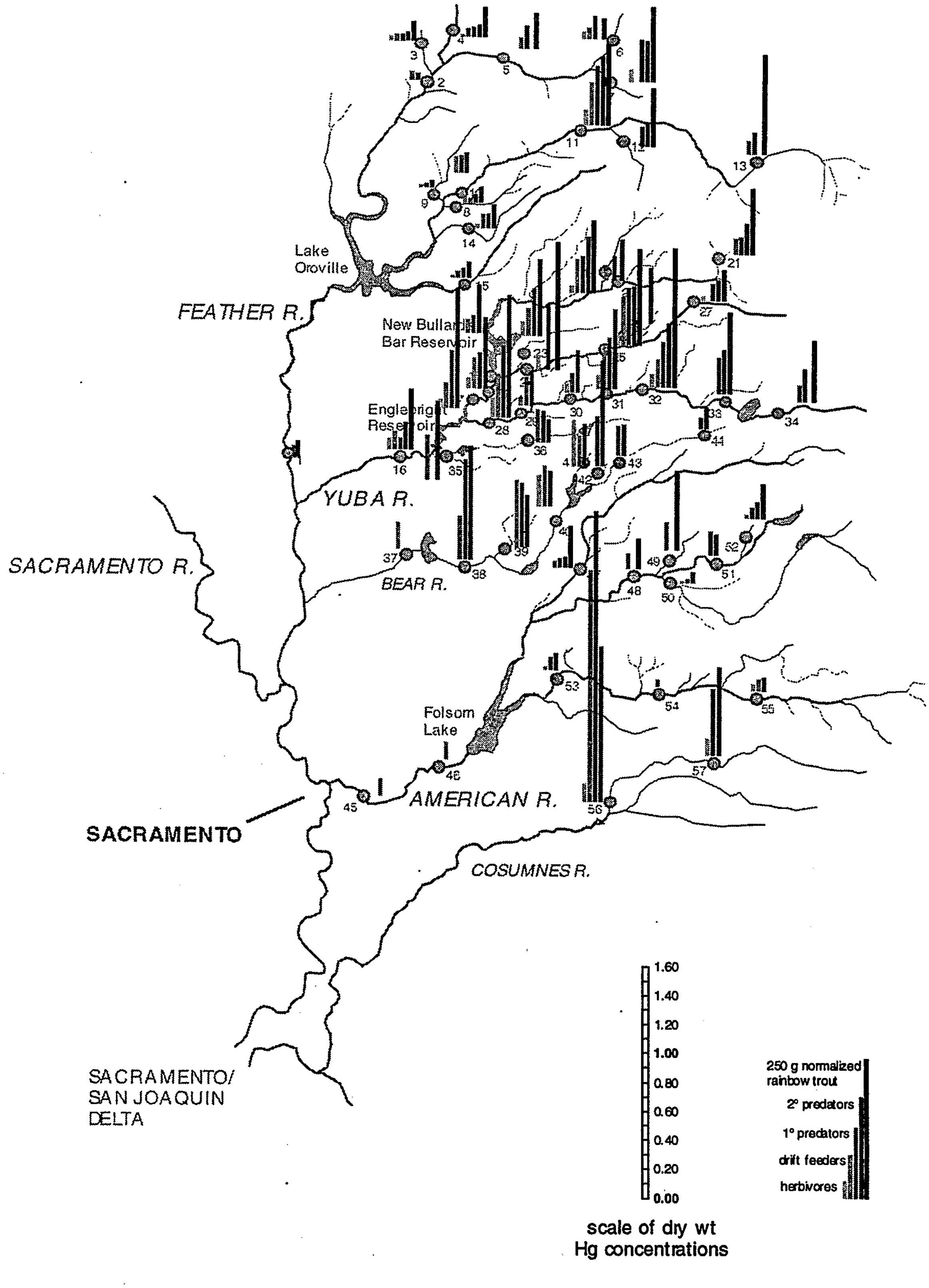


Fig. 3. Superimposed Sierra Nevada biotic mercury data for all major trophic categories

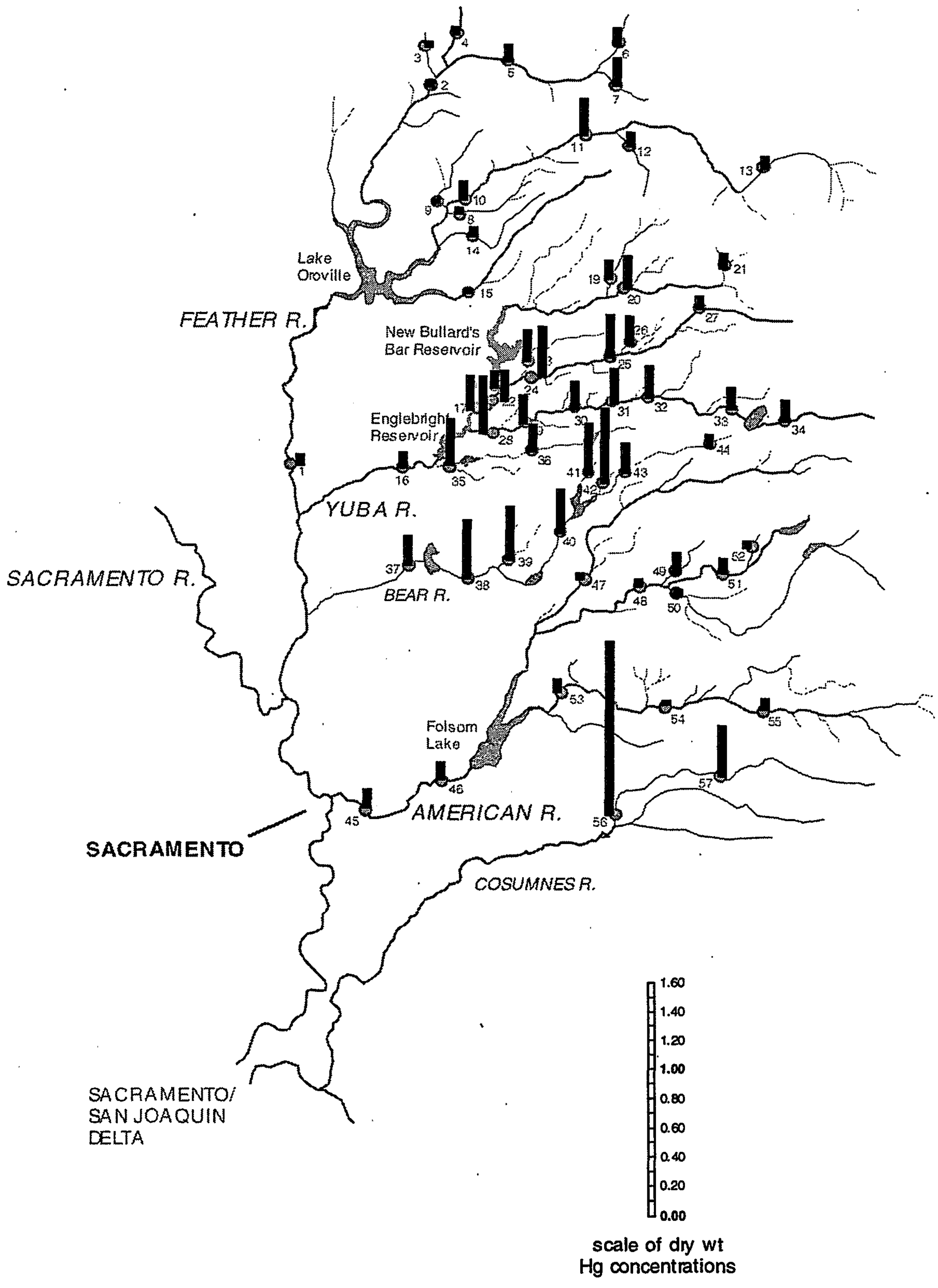


Fig. 4. Trophically Averaged Relative Mercury Levels, For Inter-Site Comparison

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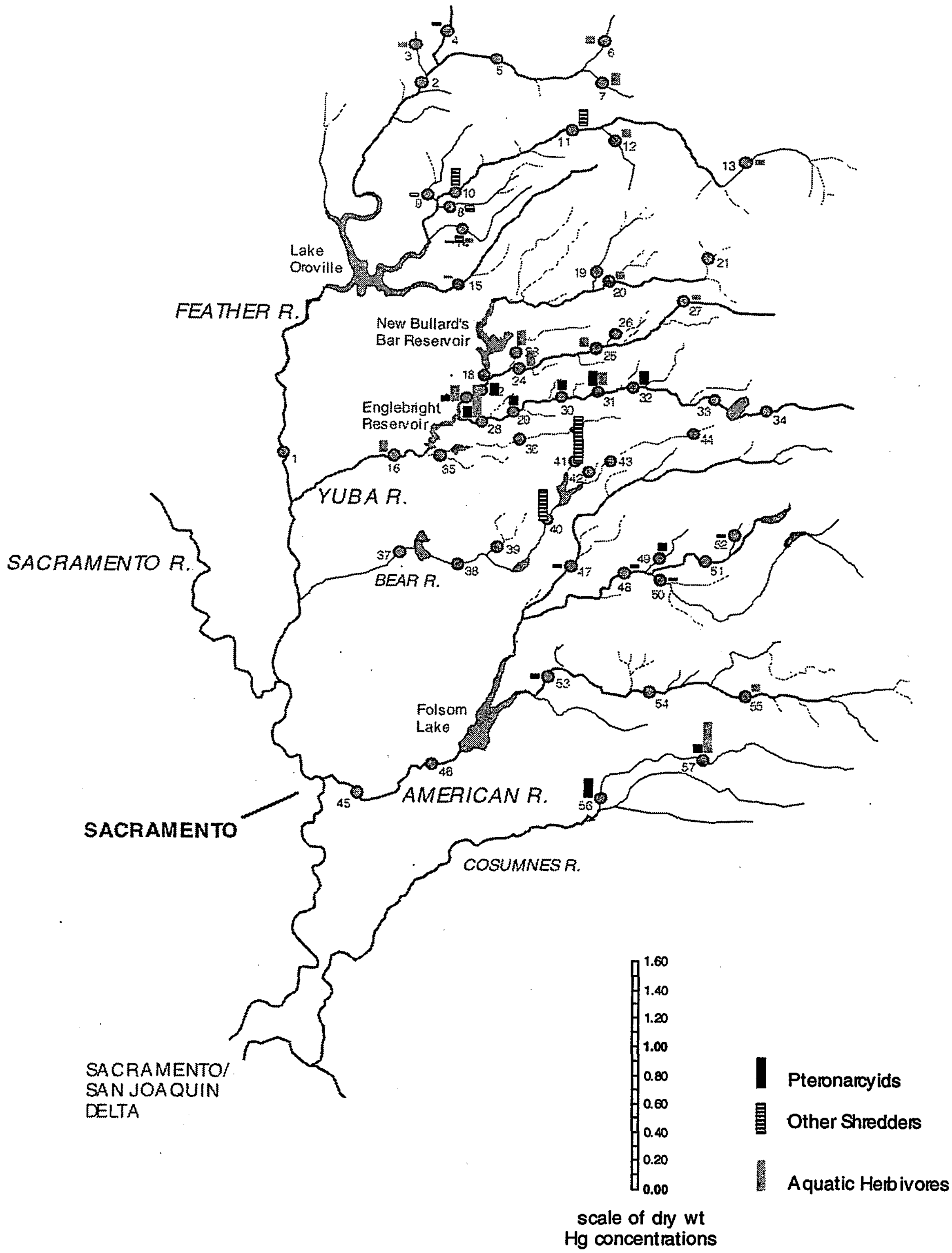

Fig. 5. Mercury in Herbivorous Stream Invertebrates (dry weight ppm)
(Shredders of terrestrial vegetation vs consumers of aquatic plants and algae)

C-035571

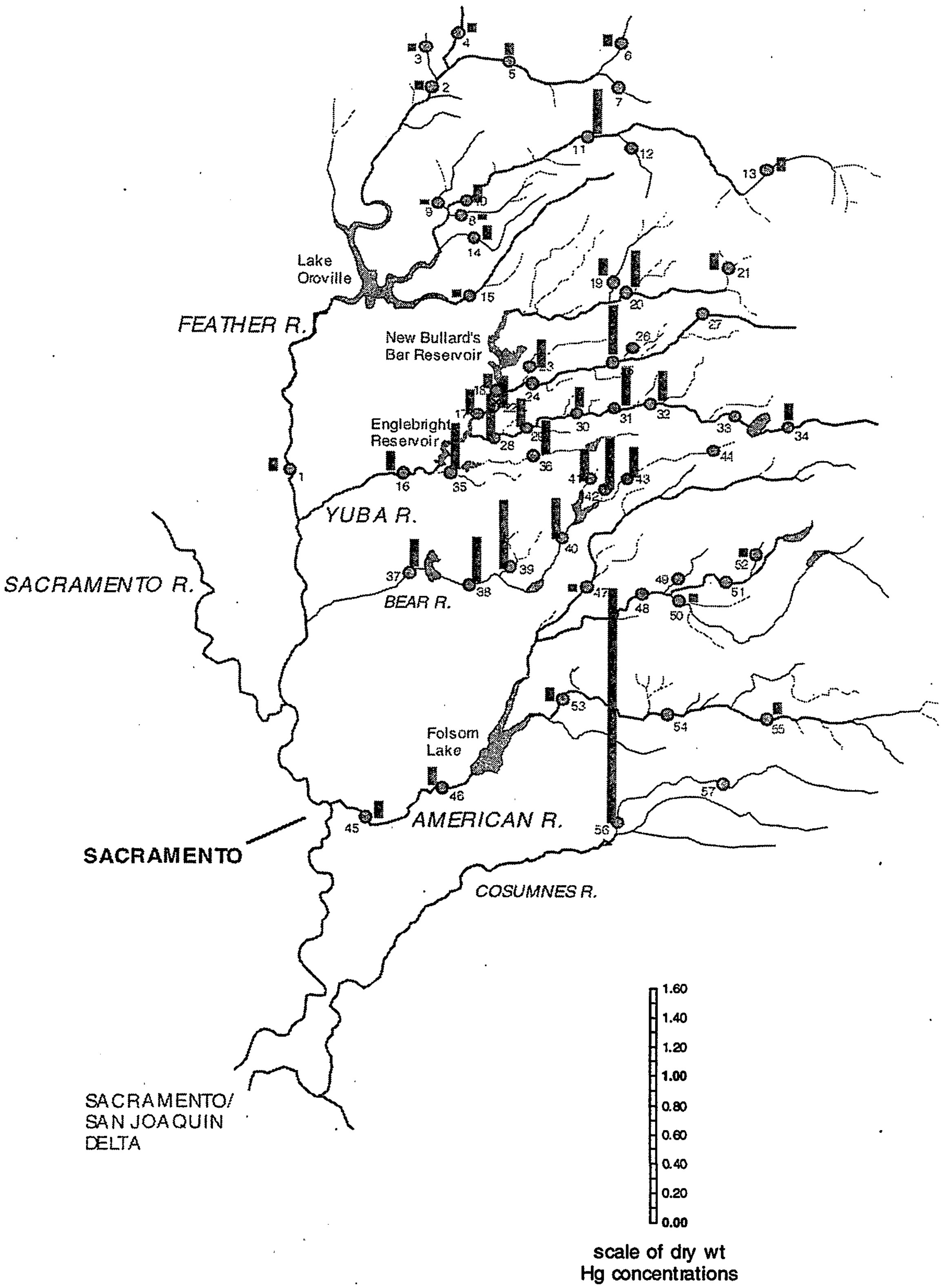

Fig. 6. Mercury in Hydropsychid Caddisfly Larvae (dry weight ppm)
(Net-utilizing drift feeders)

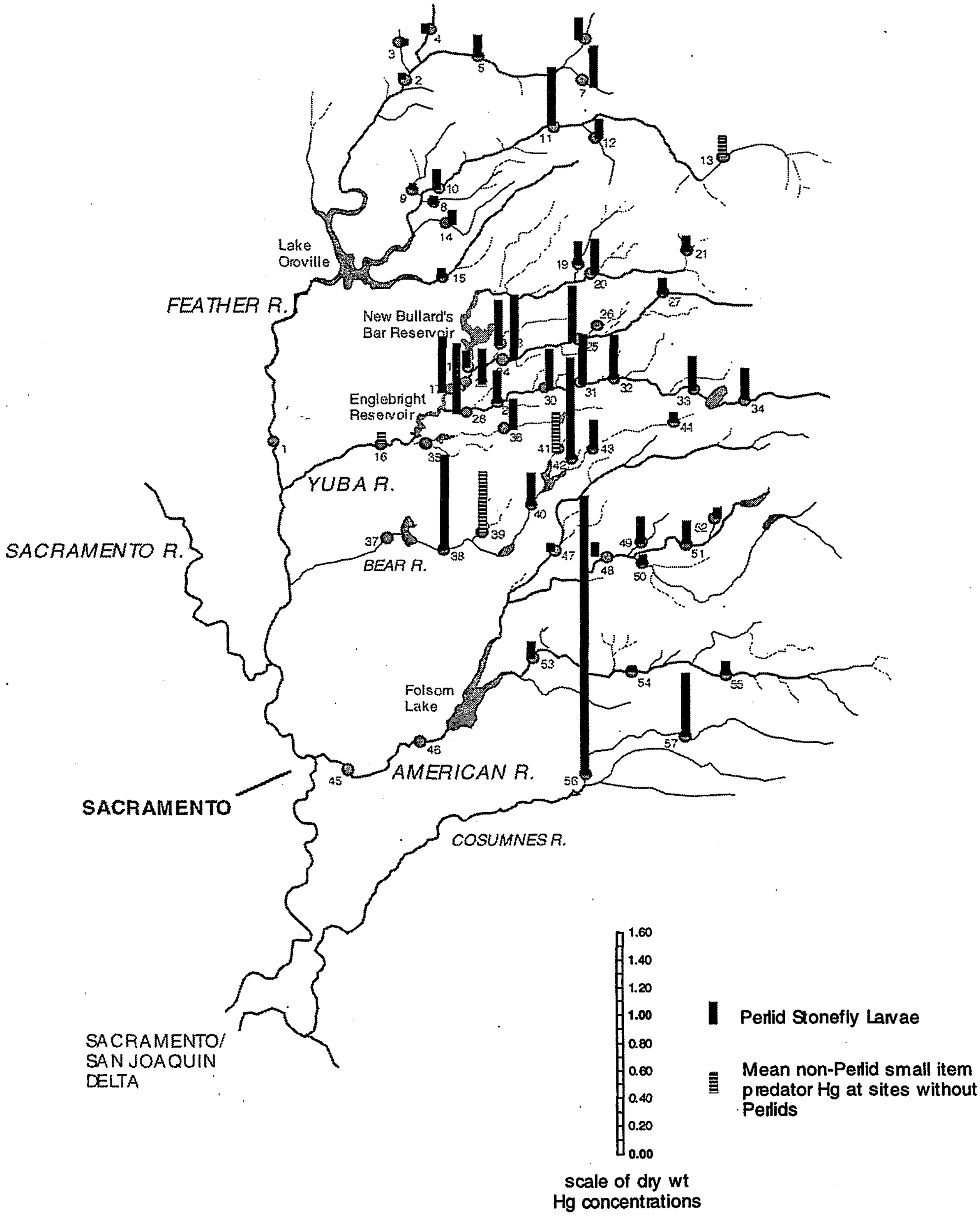

Fig. 7. Mercury in Perlid Stonefly and Other Small Item Predator Larvae (dry weight ppm)

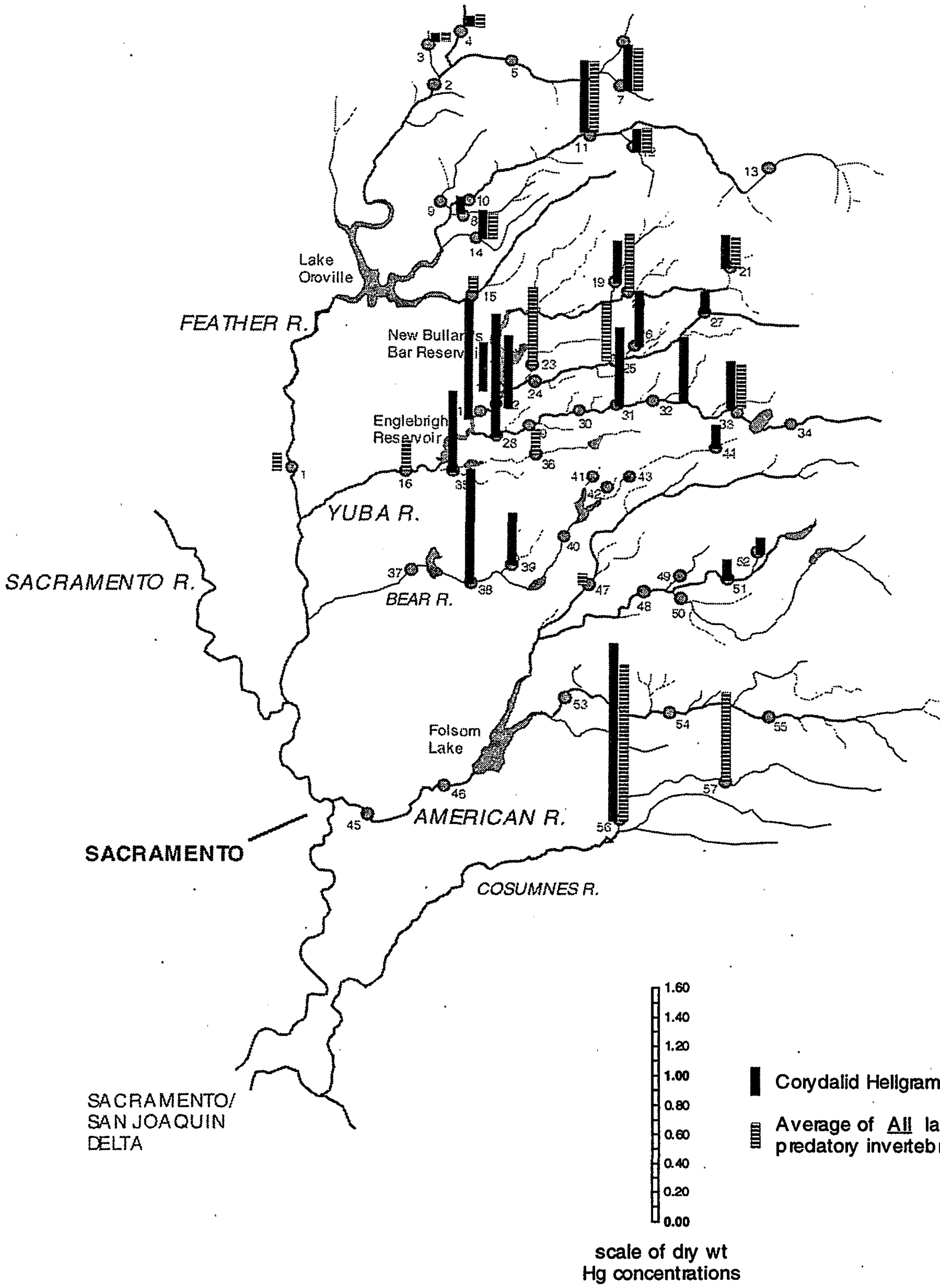

Fig. 8. Mercury in Corydalid Hellgrammite Larvae and Other Large Item Predatory Invertebrates (dry weight ppm)

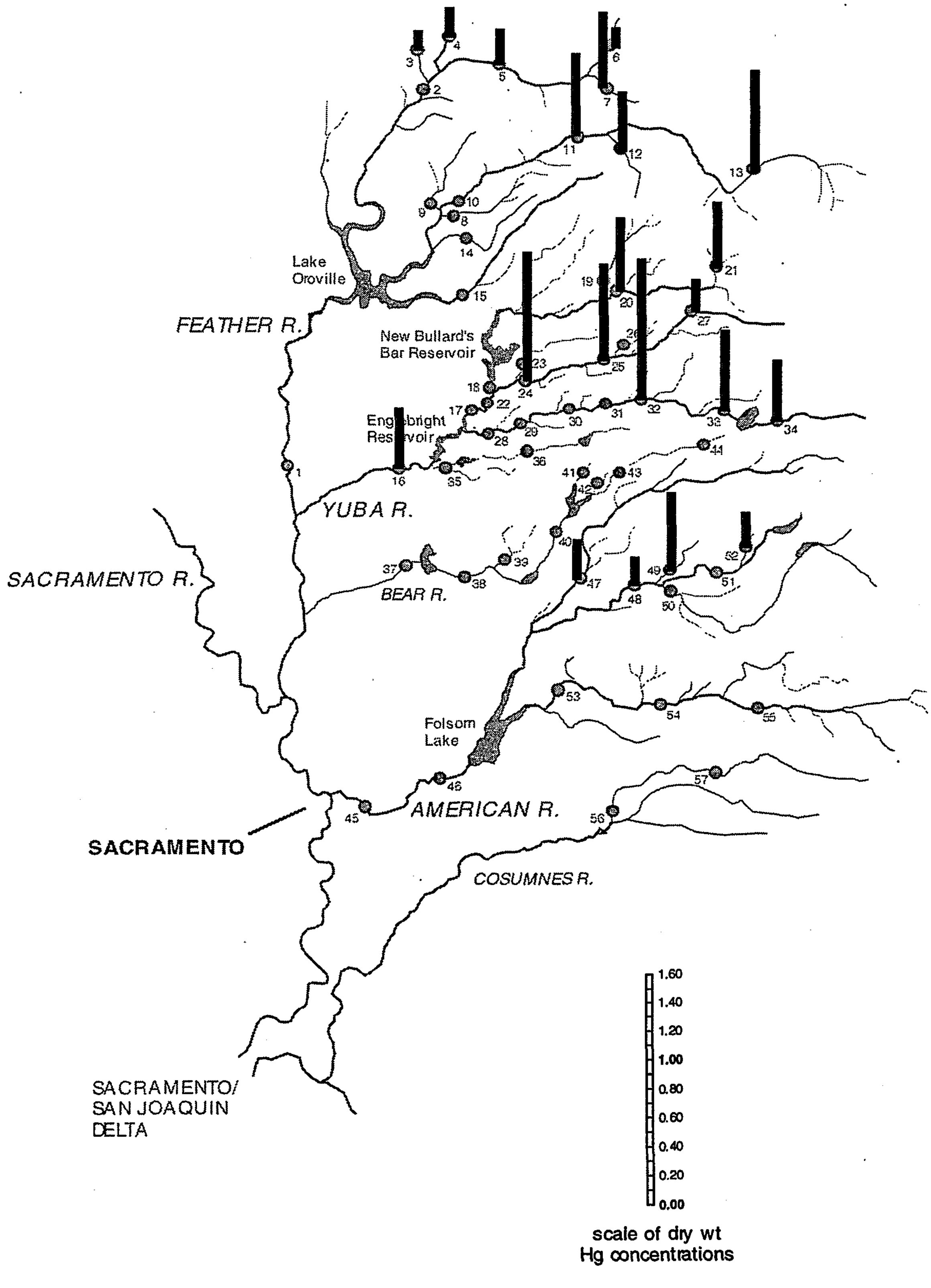

Fig. 9. Mercury in Normalized 250 g Rainbow Trout Muscle
(dry weight ppm, comparable to dry wt invertebrate data)

C-035575

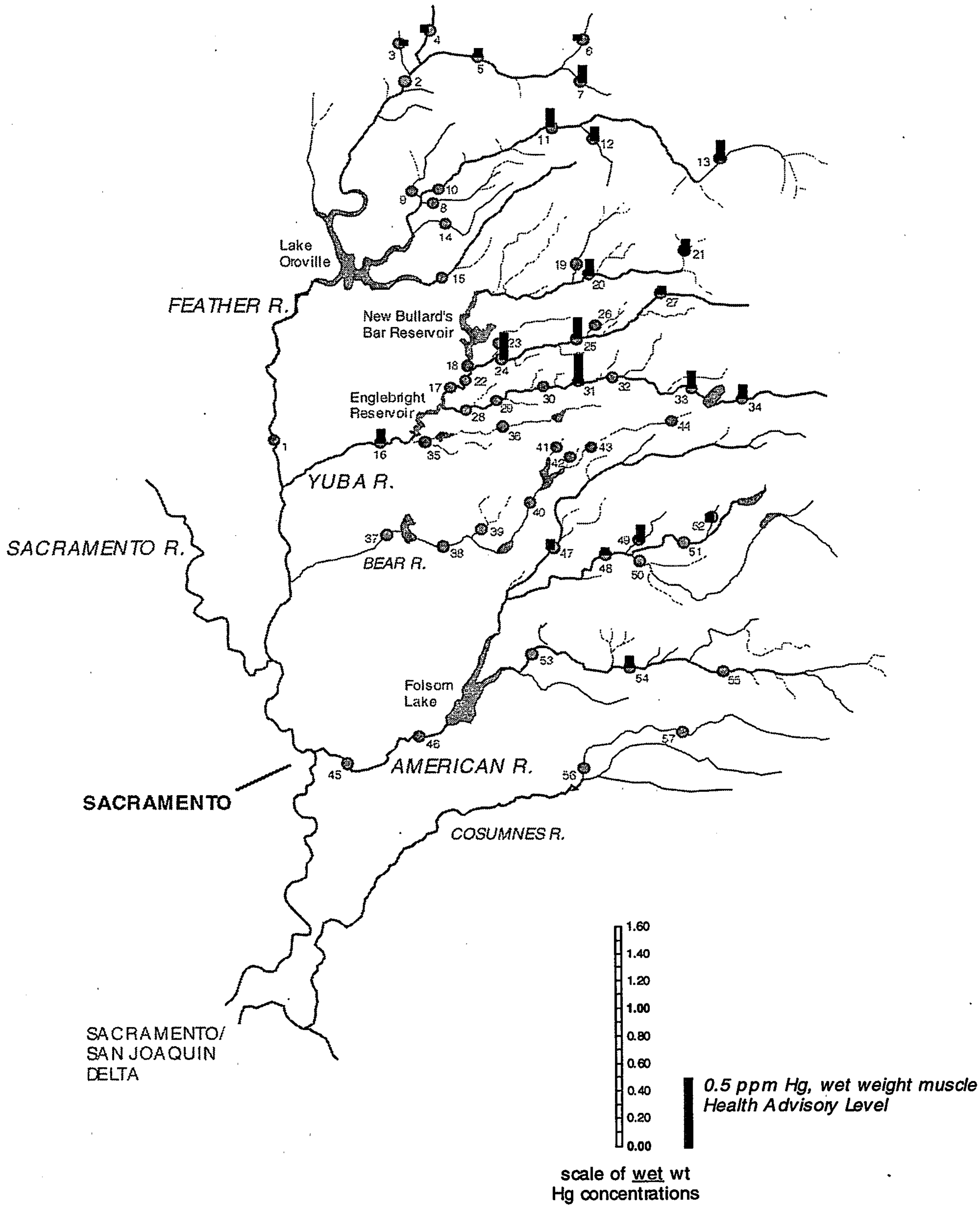

Fig. 10. Mercury in Normalized 250 g Rainbow Trout Filet Muscle
(wet weight ppm, in relation to 0.5 ppm wet weight health advisory level)

C-035576

Table 2. Biota Mercury Data For All Northwestern Sierra Nevada Project Sites (all as dry wt ppm)

identification	trophic level	Hg
1. Lower Feather River at Live Oak. (11/17/95)		
Hydropsychidae (net caddis)	drift feeder	**0.08**
Gomphidae (dragonfly nymph)	large predator	**0.10**
2. North Fork Feather River at Belden. (10/26/94)		
Hydropsychidae (net caddis)	drift feeder	**0.05**
Perlidae-Gold sp (Callineuria)	small predator	**0.04**
3. Yellow Creek (trib. of North Fk Feather R.), 2 miles above confluence. (6/11/94)		
(Large Mayflies)	herbivore	**0.03**
Hydropsychidae (net caddis)	drift feeder	**0.04**
Rhyacophyllidae (pred. caddis)	small predator	**0.04**
Perlidae (golden stonefly)	small predator	**0.03**
Corydallidae (hellgrammite)	large predator	**0.05**
Tipulidae (cranefly)	large predator	**0.06**
Mean 250 g Trout (dry ppm)	*(insect predator)*	***0.12***
(trout diet)	(trout diet)	**0.05**
4. Caribou Branch North Fork Feather River, 4 miles above confluence. (10/27/94)		
Pteronarcyidae	leaf shredder	**0.02**
Hydropsychidae (net caddis)	drift feeder	**0.05**
Perlidae-Dark sp (Hesperoperla)	small predator	**0.06**
Gomphidae (dragonfly)	large predator	**0.08**
Corydallidae (hellgrammite)	large predator	**0.07**
Tipulidae (cranefly)	large predator	**0.09**
Mean 250 g Trout (dry ppm)	*(insect predator)*	***0.20***
(trout diet)	(trout diet)	**0.06**

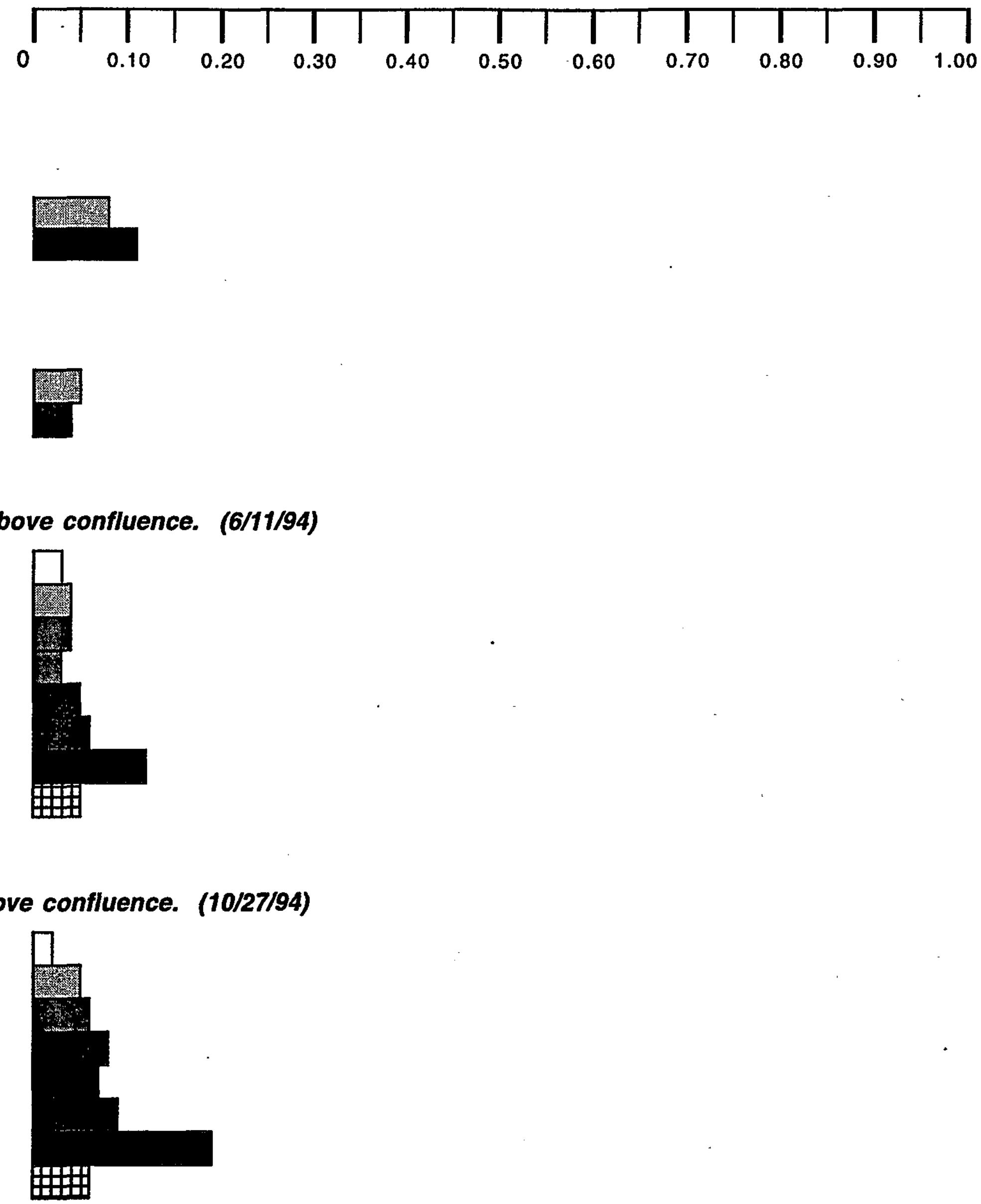

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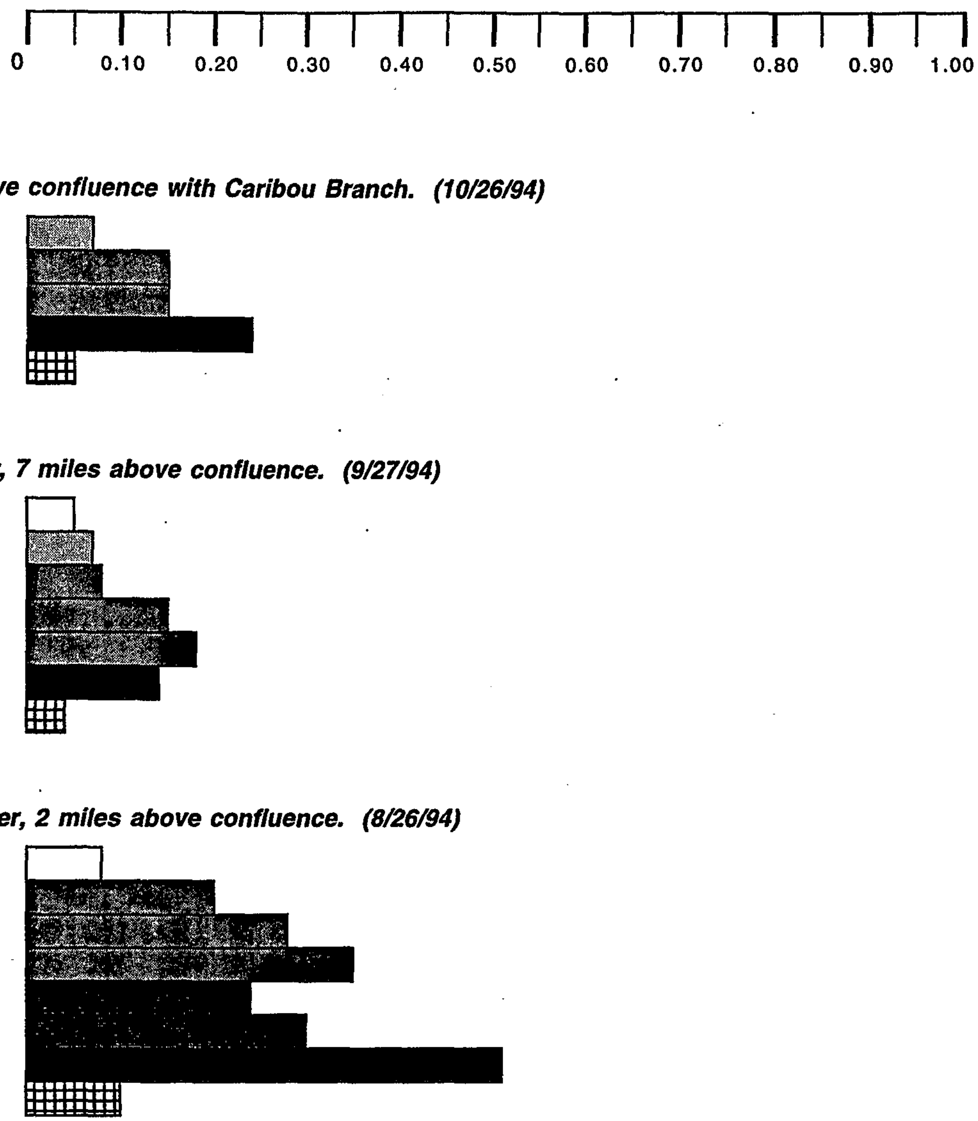
Table 2. (continued)



identification	trophic level	Hg
5. East Branch of North Fork Feather River,10 miles above confluence with Caribou Branch. (10/26/94)		
Hydropsychidae (net caddis)	drift feeder	0.07
Rhyacophyllidae (pred. caddis)	small predator	0.15
Perlidae-Dark sp (Hesperoperla)	small predator	0.15
Mean 250 g Trout (dry ppm)	*(insect predator)*	*0.24*
(trout diet)	(trout diet)	0.05
6. Indian Creek, tributary to E Branch N Fk Feather River, 7 miles above confluence. (9/27/94)		
Oligoneuriidae (mayfly)	herbivore	0.05
Hydropsychidae (net caddis)	drift feeder	0.07
Damsefly nymphs	small predator	0.08
Perlidae (golden stonefly)	small predator	0.15
Rhyacophyllidae (pred. caddis)	small predator	0.18
Mean 250 g Trout (dry ppm)	*(insect predator)*	*0.14*
(trout diet)	(trout diet)	0.04
7. Spanish Creek, tributary to E Branch N Fk Feather River, 2 miles above confluence. (8/26/94)		
Ptilodactyllidae (lg aq beetle nymph)	herbivore	0.08
Rhyacophyllidae (pred. caddis)	small predator	0.20
Damsefly nymphs	small predator	0.28
Perlidae (golden stonefly)	small predator	0.35
Gomphidae (dragonfly)	large predator	0.24
Corydallidae (hellgrammite)	large predator	0.30
Mean 250 g Trout (dry ppm)	*(insect predator)*	*0.51*
(trout diet)	(trout diet)	0.10

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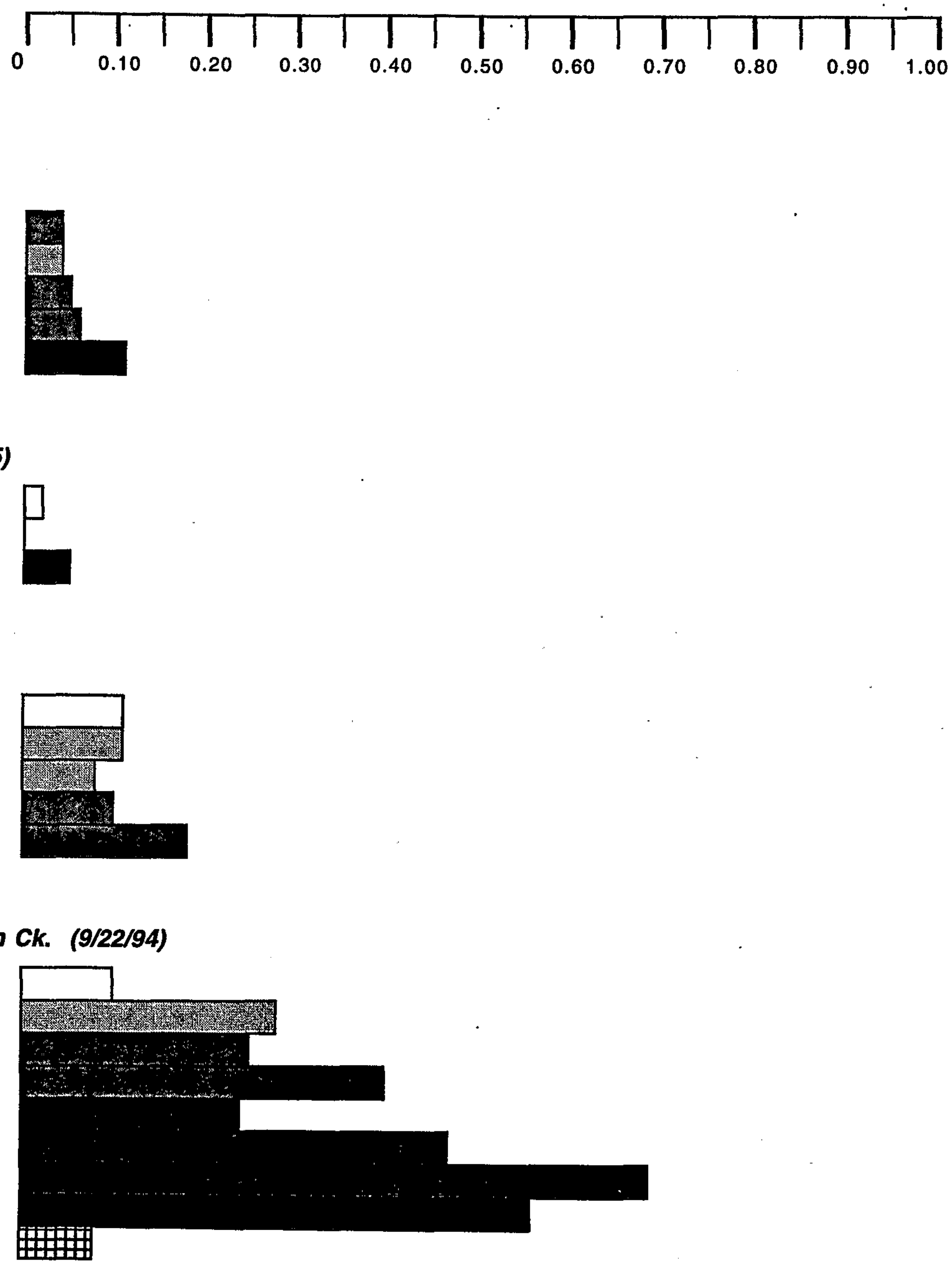
Table 2. (continued)



identification	trophic level	Hg
8. S Branch M Fk Feather at M Fk Feather. (11/21/95)		
Peltoperlidae (lg/giant)	herb/detritiv	0.04
Hydropsychidae (giant)	drift feeder	0.03
Perlidae--Callineuria (med/Lg)	small predator	0.05
Perlidae--Hesperoperla (lg)	small predator	0.06
Hellgrammite (med/lg)	large predator	0.11
9. Little N Fk M Fk Feather at M Fk Feather R. (11/21/95)		
Peltoperlidae (med/lg/giant)	herb/detritiv	0.02
Hydropsychidae (giant)	drift feeder	0.00
Perlidae (lg/giant)	small predator	0.05
10. M Fk Feather River at Milsap Bar. (11/21/95)		
Peltoperlidae (med/lg)	herb/detritiv	0.11
Hydropsychidae (med)	drift feeder	0.11
Hydropsychidae (giant)	drift feeder	0.08
Perlidae--Callineuria (lg)	small predator	0.10
Perlidae--Hesperoperla (lg)	small predator	0.18
11. Middle Fork Feather River, 1 mile below below Nelson Ck. (9/22/94)		
Pteronarcyidae	leaf shredder	0.10
Hydropsychidae (net caddis)	drift feeder	0.28
Rhyacophyllidae (pred. caddis)	small predator	0.25
Perlidae (golden stonefly)	small predator	0.40
Gomphidae (dragonfly)	large predator	0.24
Corydallidae (hellgrammite)	large predator	0.47
Tipulidae (cranefly)	large predator	0.69
Mean 250 g Trout (dry ppm)	*(insect predator)*	*0.56*
(trout diet)	(trout diet)	0.08

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Table 2. (continued)

Hg (dry wt ppm) 0 0.10 0.20 0.30 0.40 0.50 0.60 0.70 0.80 0.90 1.00

identification	trophic level	Hg
12. Nelson Creek, tributary to Middle Fork Feather River, 1 mile above confluence. (9/21/94)		
Limnephilidae (stone case caddis)	herbivore	0.05
Perlidae (golden stonefly)	small predator	0.13
Corydallidae (hellgrammite)	large predator	0.15
Tipulidae (cranefly)	large predator	0.16
Mean 250 g Trout (dry ppm)	*(insect predator)*	*0.40*
(trout diet)	(trout diet)	0.05
13. Upper Middle Fork Feather River, 3 miles upstream of Clio. (9/23/94)		
Oligoneuriidae (mayfly)	herbivore	0.03
Hydropsychidae (net caddis)	drift feeder	0.08
Damselfly Nymphs	small predator	0.13
Rhyacophyllidae (pred. caddis)	small predator	0.16
Mean 250 g Trout (dry ppm)	*(insect predator)*	*0.68*
(trout diet)	(trout diet)	0.07
14. Fall River (Feather River trib). (11/20/95)		
Pteronarcyidae (med/Lg)	leaf shredder	0.01
Mixed Mayflies (lg)	herbivore	0.03
Peltoperlidae (lg/giant)	herb/detritiv	0.05
Hydropsychidae (giant)	drift feeder	0.09
Perlidae-Callineuria (lg/giant)	small predator	0.09
Gomphidae (lg)	large predator	0.13
Hellgrammite (sm)	large predator	0.25
Hellgrammite (med/lg)	large predator	0.11

Table 2. (continued)

Hg (dry wt ppm) 0 0.10 0.20 0.30 0.40 0.50 0.60 0.70 0.80 0.90 1.00

identification	trophic level	Hg
15. South Fk Feather River. (11/20/95)		
Mayflies (lg)	herbivore	0.02
Hydropsychidae (giant)	drift feeder	0.00
Peltoperlidae (giant)	herb/detritiv	0.04
Perlidae-Callineuria (lg)	small predator	0.06
Perlidae-Callineuria (giant)	small predator	0.07
Perlidae-Hesperoperla (lg)	small predator	0.06
Hellgrammite (sm)	large predator	0.12
Hellgrammite (med)	large predator	0.09
16. Lower Yuba River below Englebright Reservoir, at University of California field station. (12/16/93)		
Ephemerellidae (mayfly)	herbivore	0.07
Hydropsychidae (net caddis)	drift feeder	0.12
Perlodidae (stonefly)	small predator	0.07
Tipulidae (cranefly)	large predator	0.18
Mean 250 g Trout (dry ppm)	*(insect predator)*	*0.42*
17. North Fk / Middle Fk Yuba River below Colgate inflow. (4/24/95)		
Pteronarcyidae-sm	leaf shredder	0.04
Mayflies	herbivore	0.10
Hydropsychidae	drift feeder	0.16
Perlodidae-sm	small predator	0.13
Perlidae-lg	small predator	0.39
Hellgrammites-lg	large predator	0.97
Hellgrammites-giant	large predator	0.68

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Table 2. (continued)

Hg (dry wt ppm) 0 0.10 0.20 0.30 0.40 0.50 0.60 0.70 0.80 0.90 1.00

18. North Fork Yuba River constrained (low) flow below New Bullard's Bar Reservoir. (3/15/94)

identification	trophic level	Hg
Hydropsychidae (net caddis)	drift feeder	0.08
Perlidae (golden stonefly)	small predator	0.11
Corydallidae (hellgrammite)	large predator	0.33

19. Canyon Creek, tributary to N Fk Yuba, just above confluence. (11/6/93)

identification	trophic level	Hg
Hydropsychidae (net caddis)	drift feeder	0.10
Perlidae (golden stonefly)	small predator	0.16
Corydallidae (hellgrammite)	large predator	0.27

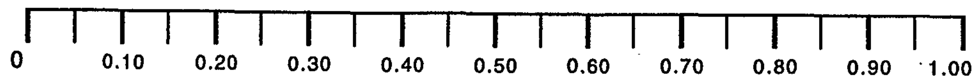
20. North Fork Yuba River, 2 miles downstream of westmost Highway 49 crossing. (11/5/93)

identification	trophic level	Hg
Pteronarcyidae (giant stonefly)	leaf shredder	0.05
Hydropsychidae (net caddis)	drift feeder	0.24
Perlidae (golden stonefly)	small predator	0.25
Tipulidae	large predator	0.38
Mean 250 g Trout (dry ppm)	*(insect predator)*	*0.50*

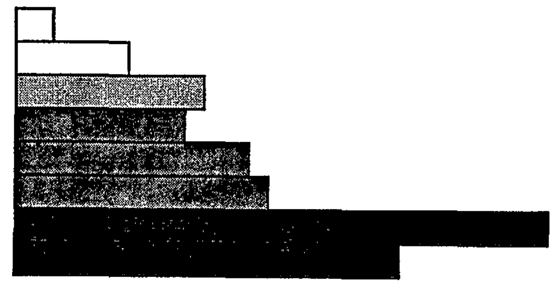
21. Downie River, tributary to N FK Yuba, at Downieville. (11/2/93)

identification	trophic level	Hg
Hydropsychidae (net caddis)	drift feeder	0.10
Perlodidae (stonefly)	small predator	0.11
Perlidae (golden stonefly)	small predator	0.11
Tipulidae (cranefly)	large predator	0.19
Corydallidae (hellgrammite)	large predator	0.22
Mean 250 g Trout (dry ppm)	*(insect predator)*	*0.45*

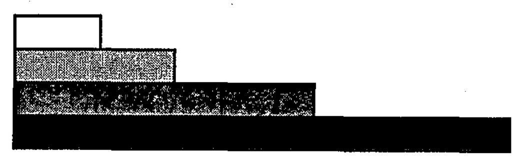
Table 2. (continued)



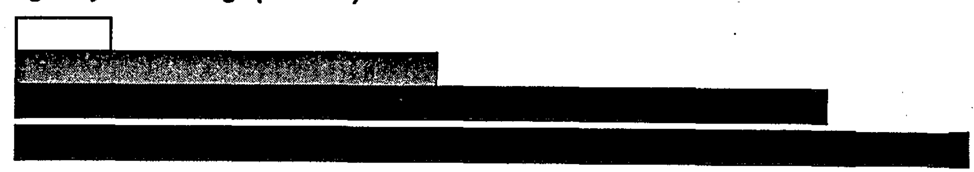
identification	trophic level	Hg
22. Middle Fork Yuba River, just upstream of Colgate inflow. (11/16/95)		
Pteronarcyidae (sm)	leaf shredder	0.04
Pteronarcyidae (Lg)	leaf shredder	0.11
Hydropsychidae	drift feeder	0.20
Perlodidae (med/Lg)	small predator	0.18
Perlidae (Lg)	small predator	0.25
Damsel nymphs	small predator	0.27
Hellgrammites (sm/Med)	large predator	0.57
Hellgrammites (Lg/giant)	large predator	0.41



identification	trophic level	Hg
23. Oregon Creek at Middle Fk Yuba. (11/9/95)		
Ptilodactylidae (lg)	herbivore	0.09
Hydropsychidae	drift feeder	0.17
Perlidae-Callineuria (med/Lg)	small predator	0.32
Tipulidae (lg)	large predator	0.53



identification	trophic level	Hg
24. Middle Fork Yuba River, just upstream of Oregon Creek and Highway 49 crossing. (10/21/93)		
Pteronarcyidae (giant stonefly)	leaf shredder	0.10
Perlidae (golden stonefly)	small predator	0.45
Mean 250 g Trout (dry ppm)	*(insect predator)*	*0.87*
Mean 250 g Squawfish	*(fish predator)*	*1.87*



identification	trophic level	Hg
25. Middle Fork Yuba River, 1 mile upstream of Tyler Foote crossing. (10/19/93)		
Pteronarcyidae (giant stonefly),1 yr	leaf shredder	0.05
Pteronarcyidae; large (2 yr)	leaf shredder	0.06
Hydropsychidae (net caddis)	drift feeder	0.33
Perlidae (golden stonefly)	small predator	0.38
Gomphidae (dragonfly)	large predator	0.39
Mean 250 g Trout (dry ppm)	*(insect predator)*	*0.66*

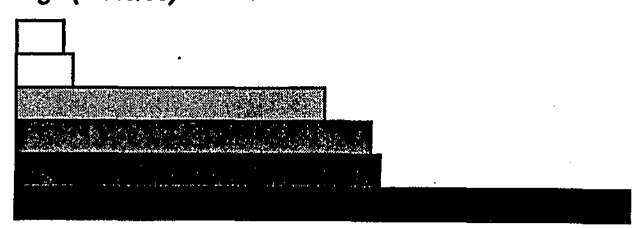


Table 2. (continued)

identification	trophic level	Hg
26. Kanaka Ck (Middle Fork Yuba trib) near M Fk Yuba. (10/14/94)		
Corydalidae	large predator	0.37
27. Middle Fork Yuba River, 1 mile upstream of Plumbago Road. (3/24/94)		
Peltoperlidae (stonefly)	herbivore	0.03
Perlidae (golden stonefly)	small predator	0.11
Corydallidae (hellgrammite)	large predator	0.14
Mean 250 g Trout (dry ppm)	*(insect predator)*	*0.20*
28. South Fork Yuba River at Bridgeport. (4/24/95)		
Pteronarcyidae-sm	leaf shredder	0.08
Mayflies	herbivore	0.27
Ptilodactylidae	herbivore	0.18
Hydropsychidae	drift feeder	0.30
Perlidae	small predator	0.50
Hellgrammites-lg	large predator	0.85
29. South Fork Yuba River at Hwy 49. (11/10/95)		
Pteronarcyidae (sm/med)	leaf shredder	0.06
Hydropsychidae	drift feeder	0.18
Perlidae (med/Lg)	small predator	0.23
30. South Fork Yuba River at Purdon Crossing. (11/10/95)		
Pteronarcyidae (lg)	leaf shredder	0.06
Hydropsychidae	drift feeder	0.13
Perlidae-Callineuria (med/lg)	small predator	0.28

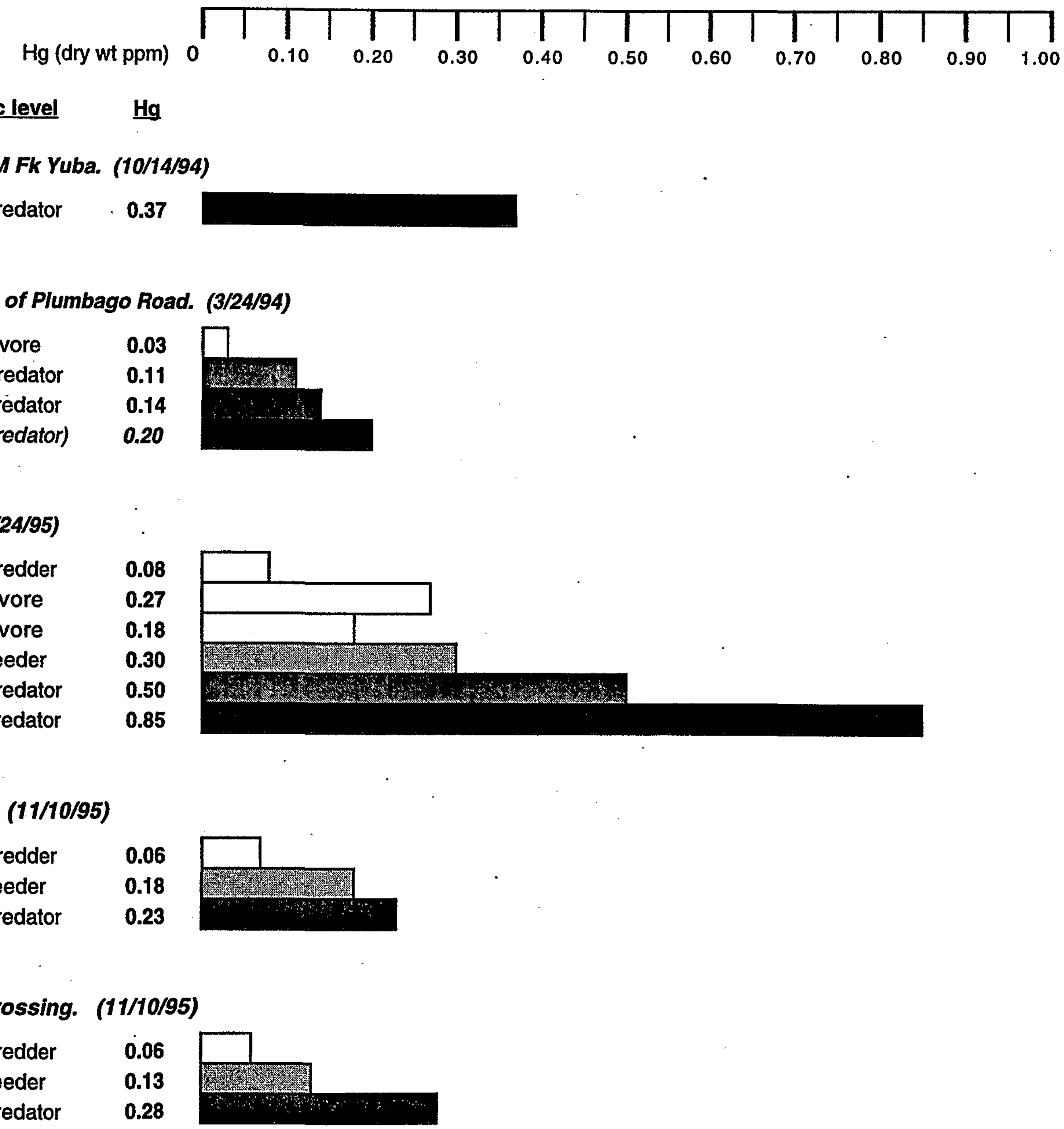


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Table 2. (continued)

Hg (dry wt ppm) 0 0.10 0.20 0.30 0.40 0.50 0.60 0.70 0.80 0.90 1.00

identification	trophic level	Hg
31. South Fork Yuba River at Edward's Crossing. (10/4/95)		
Mayflies	herbivore	0.08
Pteronarcyidae-sm	leaf shredder	0.09
Pteronarcyidae-lg	leaf shredder	0.09
Hydropsychidae-sm/med	drift feeder	0.25
Perlidae-sm	small predator	0.28
Perlidae-med	small predator	0.32
Perlidae-large	small predator	0.37
Hellgrammite-med	large predator	0.55
32. South Fork Yuba River, 1 mile downstream of Washington. (11/12/93)		
Pteronarcyidae (giant stonefly)	leaf shredder	0.08
Hydropsychidae (net caddis)	drift feeder	0.18
Perlidae (golden stonefly)	small predator	0.30
Corydallidae (hellgrammite)	large predator	0.44
Mean 250 g Trout (dry ppm)	*(insect predator)*	*0.94*
33. South Fork Yuba River below Lake Spaulding. (10/24/95)		
Perlidae (m/Lg)	small predator	0.24
Gomphidae (med)	large predator	0.24
Tipulidae (med/lg)	large predator	0.31
Hellgrammites (sm/med)	large predator	0.32
34. South Fork Yuba River 2 miles above Lake Spaulding. (10/25/95)		
Hydropsychidae (giant)	drift feeder	0.11
Perlidae (med/lg)	small predator	0.22

Table 2. (continued)

Hg (dry wt ppm) 0 0.10 0.20 0.30 0.40 0.50 0.60 0.70 0.80 0.90 1.00

identification	trophic level	Hg
35. Deer Creek below Lake Wildwood, at Mooney Flat Road. (12/9/94)		
Hydropsychidae (net caddis)	drift feeder	0.30
Corydallidae (hellgrammite)	large predator	0.55
36. Deer Creek at Bittney Spring Road. (12/9/94)		
Hydropsychidae (net caddis)	drift feeder	0.23
Perlidae (golden stonefly)	small predator	0.22
Tipulidae (cranefly)	large predator	0.16
37. Bear River below Camp Far West Reservoir. (12/8/94)		
Hydropsychidae (net caddis)	net collector	0.17
38. Bear River at Highway 49 crossing. (12/7/94)		
Hydropsychidae (net caddis)	drift feeder	0.29
Rhyacophyllidae (pred. caddis)	small predator	0.34
Perlidae-Dark sp (Hesperoperla)	smallpredator	0.69
Corydallidae (hellgrammite)	large predator	0.77
39. Wolf Creek, tributary to Bear River, 2 miles above confluence. (12/7/94)		
Hydropsychidae (net caddis)	drift feeder	0.46
Perlodidae (stonefly)	small predator	0.44
Tipulidae (cranefly)	large predator	0.35

Table 2. (continued)

identification	trophic level	Hg
40. Bear River below Rollins Reservoir. (10/12/95)		
Peltoperlidae (med/lg)	small predator	0.21
Hydropsychidae	drift feeder	0.27
Perlidae-Hesperoperla (Med/lg)	small predator	0.24
41. Greenhorn Creek (Bear River trib). (10/13/95)		
Peltoperlidae (med/lg)	small predator	0.32
Hydropsychidae	drift feeder	0.21
Damselfly Nymphs	small predator	0.28
42. Steephollow Creek (Bear River trib). (10/13/95)		
Hydropsychidae	drift feeder	0.35
Perlidae (med/lg)	small predator	0.74
43. Bear River above Rollins Reservoir. (10/13/95)		
Hydropsychidae	drift feeder	0.20
Perlidae-Callineuria (med/Lg)	small predator	0.21
44. Bear River headwaters near Lake Spaulding. (10/24/95)		
Perlidae (med/Lg)	small predator	0.07
Hellgrammites (lg)	large predator	0.15
45. Lower American River at Howe Avenue. (12/16/94)		
Hydropsychidae (net caddis)	drift feeder	0.11

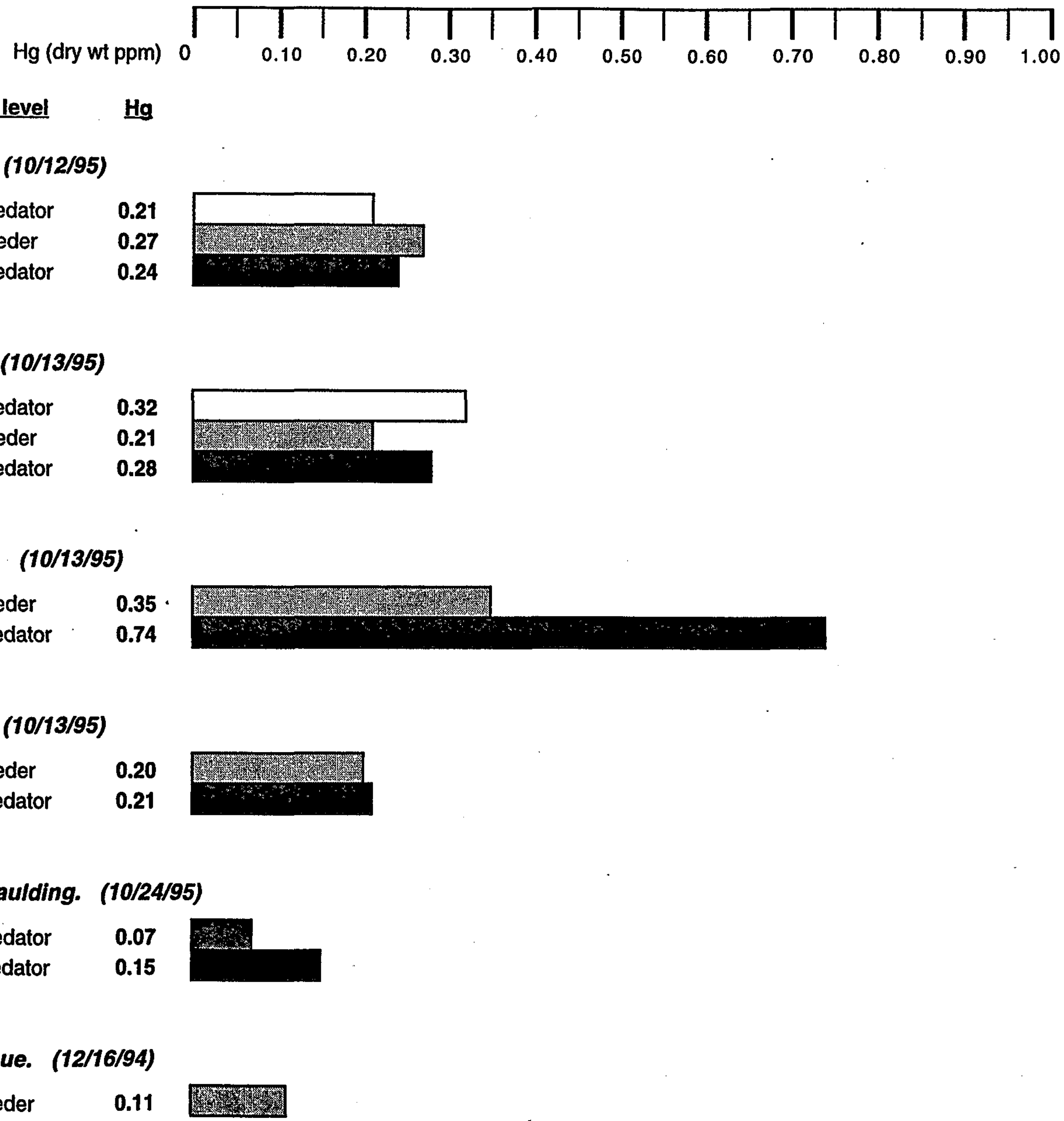

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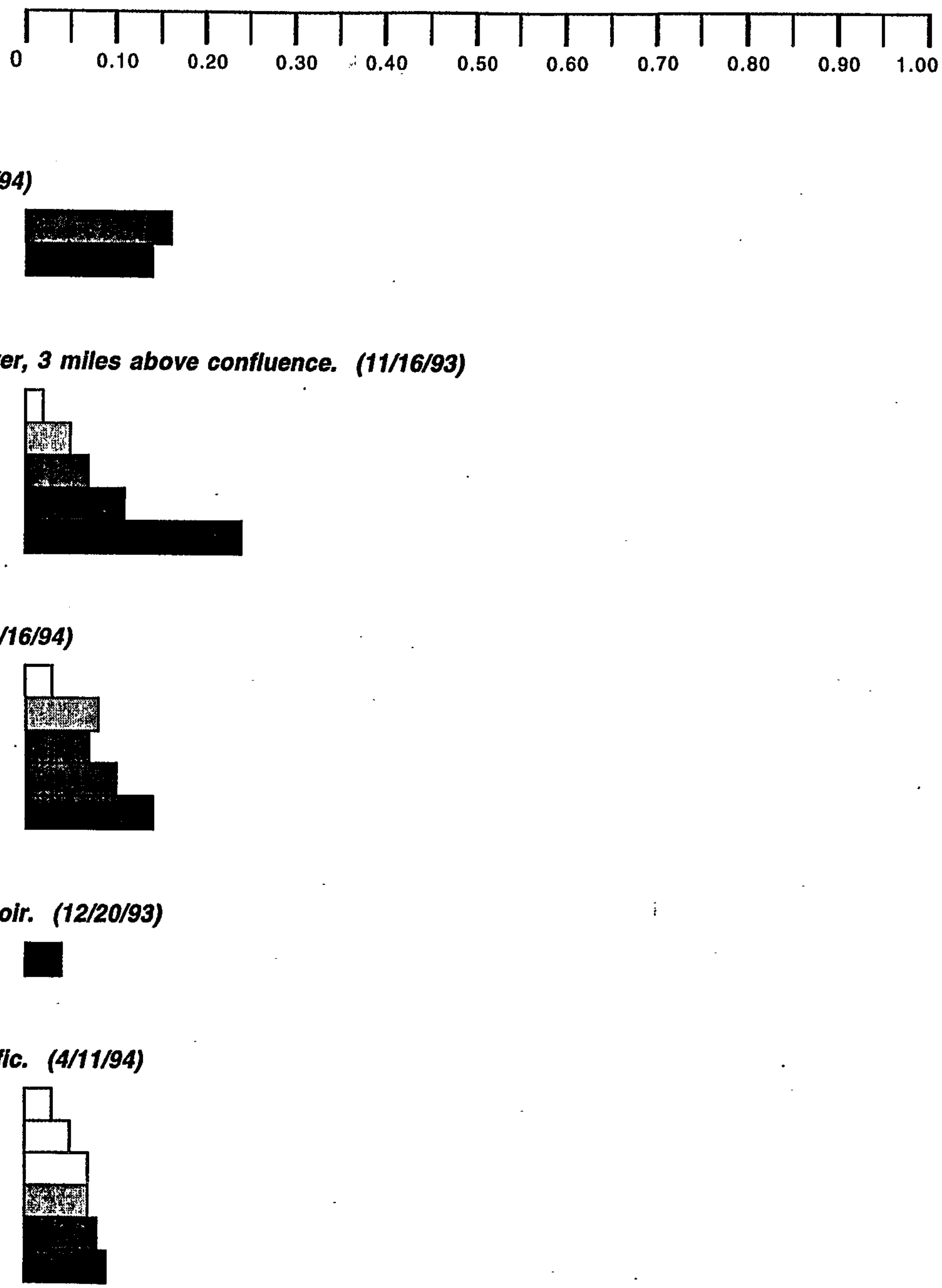
Table 2. (continued)

Hg (dry wt ppm) 0 0.10 0.20 0.30 0.40 0.50 0.60 0.70 0.80 0.90 1.00

identification	trophic level	Hg
46. Lower American River, 1 mile below Lake Natoma. (12/16/94)		
Hydropsychidae (net caddis)	drift feeder	0.11
47. North Fork American River in vicinity of Humbug Bar. (11/19/93)		
Pteronarcyidae (giant stonefly)	leaf shredder	0.02
Hydropsychidae (net caddis)	drift feeder	0.04
Perlidae-Gold sp (Callineuria)	small predator	0.05
Perlidae-Dark sp (Hesperoperla)	small predator	0.06
Gomphidae (dragonfly)	large predator	0.07
Mean 250 g Trout (dry ppm)	*(insect predator)*	*0.27*
48. Middle Fork American River below Oxbow Reservoir. (2/25/94)		
Pteronarcyidae (giant stonefly)	leaf shredder	0.02
Perlodidae (stonefly)	herbivore	0.05
Perlidae (golden stonefly)	small predator	0.09
Mean 250 g Trout (dry ppm)	*(insect predator)*	*0.20*
950 g Brown Trout (dry ppm)	*(fish predator)*	*1.68*
49. North Fork of the Middle Fk American River, 1 mile above confluence. (3/2/94)		
Pteronarcyidae (giant stonefly)	leaf shredder	0.05
Perlidae (golden stonefly)	small predator	0.18
Mean 250 g Trout (dry ppm)	*(insect predator)*	*0.55*
50. Rubicon River, tributary to Middle Fork American River, just above confluence. (2/1/94)		
Pteronarcyidae (giant stonefly)	leaf shredder	0.02
Perlodidae (stonefly)	herbivore	0.03
Hydropsychidae (net caddis)	drift feeder	0.05
Perlidae (golden stonefly)	small predator	0.07

Table 2. (continued)



identification	trophic level	Hg
51. Middle Fork American River at "End of World". (2/1/94)		
Perlidae (golden stonefly)	small predator	0.16
Corydallidae (hellgrammite)	large predator	0.14
52. Duncan Creek, tributary to Middle Fork American River, 3 miles above confluence. (11/16/93)		
Peltoperlidae (stonefly)	herbivore	0.02
Hydropsychidae (net caddis)	drift feeder	0.05
Perlidae (golden stonefly)	small predator	0.07
Corydallidae (hellgrammite)	large predator	0.11
Mean 250 g Trout (dry ppm)	*(insect predator)*	*0.24*
53. South Fork American River above Folsom Lake. (12/16/94)		
Pteronarcyidae	leaf shredder	0.03
Hydropsychidae (net caddis)	drift feeder	0.08
Perlodidae- Osobenus	small predator	0.07
Perlidae-Gold sp (Callineuria)	small predator	0.10
Perlidae-Dark sp (Hesperoperla)	small predator	0.14
54. South Fork American River below Slab Creek Reservoir. (12/20/93)		
Perlidae (golden stonefly)	small predator	0.04
55. South Fork American River, 1 mile upstream of Pacific. (4/11/94)		
Heptageneidae (mayfly)	herbivore	0.03
Ephemerellidae (mayfly)	herbivore	0.05
Ptilodactylidae (lg aq beetle nymph)	herbivore	0.07
Hydropsychidae (net caddis)	drift feeder	0.07
Perlidae-Gold sp (Callineuria)	small predator	0.08
Perlidae-Dark sp (Hesperoperla)	small predator	0.09

Table 2. (continued)

56. *North Fork Cosumnes River just above M Fk confluence. (7/30/95)*

identification	trophic level	Hg
Pteronarcyidae-sm	leaf shredder	0.12
Hydropsychidae-med	drift feeder	1.62
Perlidae-med	small predator	2.02
Gomphidae	large predator	0.90
Hellgrammite-sm	large predator	1.23

57. *North Fork Cosumnes River at Mt. Aukum Rd. (12/20/93)*

identification	trophic level	Hg
Pteronarcyidae (giant stonefly)	leaf shredder	0.05
Ptilodactylidae (lg aq beetle nymph)	herbivore	0.20
Perlodidae (stonefly)	herbivore	0.21
Perlidae-Dark sp (Hesperoperla)	small predator	0.38
Perlidae-Gold sp (Callineuria)	small predator	0.52
Gomphidae (dragonfly)	large predator	0.60

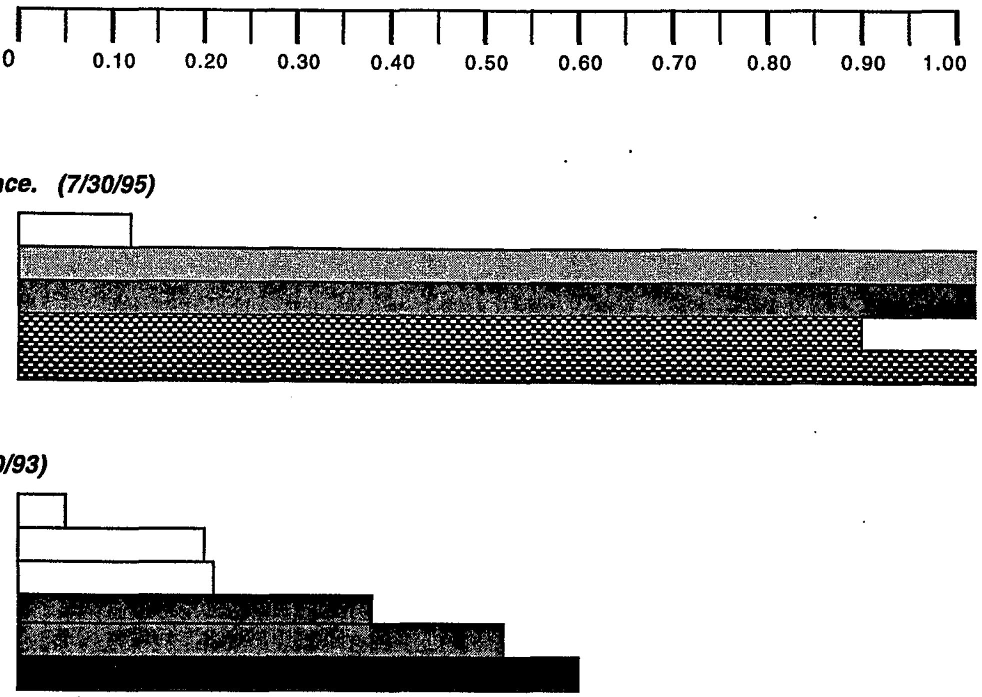


TABLE 3. Mercury Data From Individual Fish

wt (g)	Length (mm)	Sex	Muscle ppm Hg	Liver ppm Hg
2. Yellow Ck (off N Fk Feather River), 6/11/94				
107 g	197	f	**0.02**	
150 g	230	m	**0.02**	
210 g	257	f	**0.02**	
245 g	270	f	**0.03**	
280 g	285	f	**0.03**	
280 g	288	m	**0.03**	
315 g	297	f	**0.03**	
normalized 250 g trout muscle (wet wt ppm Hg):			***0.03***	
normalized 250 g trout muscle (dry wt ppm Hg):			***0.12***	
3. Caribou N Fk Feather River, 10/27/94				
75 g	190	m	**0.03**	
115 g	223	f	**0.03**	
120 g	223	m	**0.02**	
210 g	266	m	**0.04**	
240 g	274	m	**0.04**	
normalized 250 g trout muscle (wet wt ppm Hg):			***0.04***	
normalized 250 g trout muscle (dry wt ppm Hg):			***0.20***	
4. E Branch N Fk Feather River, 10/26/94				
75 g	193	m	**0.04**	
160 g	248	m	**0.03**	
207 g	266	f	**0.04**	
423 g	348	m	**0.05**	
515 g	370	f	**0.07**	
627 g	385	f	**0.12**	
normalized 250 g trout muscle (wet wt ppm Hg):			***0.05***	
normalized 250 g trout muscle (dry wt ppm Hg):			***0.24***	
5. Indian Ck (Trib, E Branch N Fk Feather River), 9/27/94				
151 g	242	f	**0.03**	
153 g	243	f	**0.02**	
335 g	304	m	**0.03**	
normalized 250 g trout muscle (wet wt ppm Hg):			***0.03***	
normalized 250 g trout muscle (dry wt ppm Hg):			***0.14***	

TABLE 3. (continued)

wt (g)	Length (mm)	Sex	Muscle ppm Hg	Liver ppm Hg
6. Spanish Ck (Trib, E Branch N Fk Feather River), 9/26/94				
139 g	241	f	0.10	
133 g	238	m	0.13	
164 g	250	f	0.06	
185 g	258	f	0.09	
285 g	298	f	0.06	
normalized 250 g trout muscle (wet wt ppm Hg):			***0.11***	
normalized 250 g trout muscle (dry wt ppm Hg):			***0.51***	
11. Middle Fk Feather River (Below Nelson Ck), 9/22/94				
74 g	195	m	0.12	
109 g	223	?	0.09	
137 g	238	m	0.10	
170 g	245	m	0.17	
273 g	294	m	0.09	
normalized 250 g trout muscle (wet wt ppm Hg):			***0.12***	
normalized 250 g trout muscle (dry wt ppm Hg):			***0.56***	
12. Nelson Ck (Tributary to M Fk Feather River), 9/21/94				
60 g	185	?	0.07	
160 g	245	m	0.07	
230 g	292	f	0.09	
305 g	304	f	0.10	
340 g	325	m	0.23	
430 g	338	f	0.06	
normalized 250 g trout muscle (wet wt ppm Hg):			***0.09***	
normalized 250 g trout muscle (dry wt ppm Hg):			***0.40***	
13. Upper Middle Fk Feather River, Above Clio, 9/23/94				
70 g	176	m	0.09	
112 g	210	m	0.08	
144 g	222	f	0.10	
137 g	224	f	0.14	
174 g	245	f	0.17	
normalized 250 g trout muscle (wet wt ppm Hg):			***0.15***	
normalized 250 g trout muscle (dry wt ppm Hg):			***0.68***	

TABLE 3. (continued)

wt (g)	Length (mm)	Sex	Muscle ppm Hg	Liver ppm Hg
16. Lower Yuba below Engelbright Reservoir,12/16/93				
170 g	235	f	**0.09**	0.11
235 g	274	m	**0.13**	0.09
255 g	272	f	**0.07**	0.08
400 g	314	f	**0.10**	0.09
440 g	329	m	**0.07**	0.08
565 g	370	m	**0.11**	0.06
860 g	408	f	**0.13**	0.09
910 g	417	m	**0.12**	0.08
1040 g	434	m	**0.12**	0.07
normalized 250 g trout muscle (wet wt ppm Hg):			***0.09***	
normalized 250 g trout muscle (dry wt ppm Hg):			***0.42***	
20. North Fork Yuba River Near Canyon Creek, 11/5/93				
145 g	236	f	**0.14**	0.16
200 g	270	f	**0.09**	0.08
300 g	306	f	**0.10**	0.10
320 g	314	f	**0.11**	0.13
340 g	311	m	**0.10**	0.07
normalized 250 g trout muscle (wet wt ppm Hg):			***0.11***	
normalized 250 g trout muscle (dry wt ppm Hg):			***0.50***	
19. Canyon Creek at N Fk Yuba,11/6/93				
305 g	294	m	**0.11**	0.10
21. Downie River (tributary of N Fk Yuba), 11/2/93				
55 g	176	m	**0.04**	0.04
85 g	195	m	**0.06**	0.04
150 g	239	f	**0.08**	0.06
155 g	243	m	**0.06**	0.05
410 g	356	f	**0.15**	0.13
465 g	348	m	**0.07**	0.06
normalized 250 g trout muscle (wet wt ppm Hg):			***0.10***	
normalized 250 g trout muscle (dry wt ppm Hg):			***0.45***	

TABLE 3. (continued)

wt (g)	Length (mm)	Sex	Muscle ppm Hg	Liver ppm Hg
24. Middle Fork Yuba above Oregon Creek, 10/21/93				
Rainbow Trout				
100 g	204	f	**0.15**	0.12
260 g	260	m	**0.21**	0.19
250 g	278	f	**0.17**	0.20
normalized 250 g trout muscle (wet wt ppm Hg):			***0.19***	
normalized 250 g trout muscle (dry wt ppm Hg):			***0.87***	
Squawfish				
370 g	321	m	**0.56**	0.33
480 g	339	f	**0.81**	0.42
25. Middle Fork Yuba above Kanaka Creek, 10/93				
94 g	210	m	**0.10**	0.09
130 g	235	f	**0.12**	0.10
135 g	237	m	**0.12**	0.09
150 g	240	m	**0.13**	0.12
320 g	298	m	**0.13**	0.19
375 g	320	f	**0.20**	0.17
505 g	368	m	**0.21**	(Lost Liver)
515 g	363	m	**0.24**	0.30
615 g	387	m	**0.21**	0.19
normalized 250 g trout muscle (wet wt ppm Hg):			***0.15***	
normalized 250 g trout muscle (dry wt ppm Hg):			***0.66***	
27. Middle Fork Yuba above Plumbago Rd, 3/24/94				
270 g	292	f	**0.05**	0.04
380 g	346	f	**0.06**	0.06
580 g	385	m	**0.12**	0.08
710 g	391	f	**0.12**	0.09
730 g	415	f	**0.19**	0.20
normalized 250 g trout muscle (wet wt ppm Hg):			***0.05***	
normalized 250 g trout muscle (dry wt ppm Hg):			***0.20***	

TABLE 3. (continued)

wt (g)	Length (mm)	Sex	Muscle ppm Hg	Liver ppm Hg
32. South Fork Yuba at Washington, 11/12/93				
20 g	112	?	**0.14**	(not analyzed)
70 g	183	f	**0.13**	0.11
70 g	186	?	**0.12**	0.14
85 g	195	?	**0.12**	0.15
90 g	200	m	**0.11**	0.13
90 g	201	?	**0.11**	0.13
90 g	207	f	**0.12**	0.16
100 g	205	?	**0.11**	0.12
135 g	234	m	**0.10**	0.12
140 g	230	m	**0.13**	0.15
150 g	237	f	**0.11**	0.13
230 g	274	f	**0.22**	0.22
310 g	305	f	**0.26**	0.35
450 g	345	f	**0.30**	0.48
normalized 250 g trout muscle (wet wt ppm Hg):			***0.21***	
normalized 250 g trout muscle (dry wt ppm Hg):			***0.94***	
33. South Fork Yuba below Lake Spaulding, 10/24/95				
Rainbow Trout				
22 g	131		**0.04**	
75 g	180		**0.06**	
85 g	190		**0.08**	
130 g	228		**0.11**	
normalized 250 g trout muscle (wet wt ppm Hg):			***0.12***	
normalized 250 g trout muscle (dry wt ppm Hg):			***0.56***	
Brown Trout				
125 g	224		**0.07**	
190 g	248		**0.07**	
34. South Fork Yuba above Lake Spaulding, 10/24/95				
Brown Trout				
99 g	208	f	**0.06**	
101 g	211	f	**0.09**	
155 g	247	f	**0.08**	
189 g	264	f	**0.06**	
normalized 250 g trout muscle (wet wt ppm Hg):			***0.09***	
normalized 250 g trout muscle (dry wt ppm Hg):			***0.43***	
40. Bear River below Rollins Reservoir, 10/13/95				
101 g	209		**0.16**	

TABLE 3. (continued)

wt (g)	Length (mm)	Sex	Muscle ppm Hg	Liver ppm Hg
47. North Fork American River above Humbug Bar, 11/19/93				
110 g	216	f	**0.03**	0.02
140 g	237	f	**0.05**	0.03
150 g	245	m	**0.03**	0.03
595 g	384	m	**0.15**	0.14
normalized 250 g trout muscle (wet wt ppm Hg):			***0.06***	
normalized 250 g trout muscle (dry wt ppm Hg):			***0.27***	
48. Middle Fk American River Below Oxbow Reservoir, 2/25/94				
Rainbow Trout				
295 g	297	f	**0.05**	0.04
330 g	308	f	**0.06**	0.05
335 g	313	f	**0.06**	0.05
385 g	327	f	**0.06**	0.05
385 g	332	f	**0.04**	0.05
400 g	334	m	**0.07**	0.05
normalized 250 g trout muscle (wet wt ppm Hg):			***0.04***	
normalized 250 g trout muscle (dry wt ppm Hg):			***0.20***	
Brown Trout				
965 g	452	f	**0.37**	0.67
49. N Fk Middle Fk American River--Middle Fk up to Skunk Ck, 3/2/94				
90 g	211	f	**0.11**	0.08
120 g	227	f	**0.10**	0.08
160 g	247	f	**0.11**	0.07
normalized 250 g trout muscle (wet wt ppm Hg):			***0.12***	
normalized 250 g trout muscle (dry wt ppm Hg):			***0.55***	

TABLE 3. (continued)

wt (g)	Length (mm)	Sex	Muscle ppm Hg	Liver ppm Hg
52. Duncan Creek (tributary of Middle Fk American R.), 11/16/93				
Rainbow Trout				
35 g	149	m	**0.02**	0.02
55 g	170	f	**0.02**	0.02
80 g	186	f	**0.03**	0.04
85 g	195	f	**0.03**	0.03
100 g	205	m	**0.03**	0.03
100 g	215	m	**0.04**	0.05
120 g	223	m	**0.03**	0.03
170 g	246	m	**0.04**	0.05
normalized 250 g trout muscle (wet wt ppm Hg):			***0.05***	
normalized 250 g trout muscle (dry wt ppm Hg):			***0.24***	
Brown Trout				
55 g	173	m	**0.03**	0.04
110 g	214	f	**0.04**	0.04
135 g	230	m	**0.05**	0.04
150 g	237	m	**0.04**	0.05
54. South Fk American River Below Slab Creek Reservoir, 12/20/93				
Rainbow Trout				
86 g	197	m	**0.07**	0.06
Brown Trout				
83 g	207	m	**0.06**	0.06

section of the Middle Fork of the Feather River (Site 11). These sites were among those noted in the course of the study as having the greatest current mining activity. They also include some of the historically most intensively mined regions. Low mercury concentrations (≤ 0.06 mg kg^{-1}, normalized) were found in trout from many tributaries of the Feather and American rivers, as well as upstream of the major mining activity along the Middle Fork of the Yuba River. Fish from the North Fork of the Middle Fork of the American River (Site 49) and Spanish Creek (Site 7), a tributary to the North Fork Feather River, were relatively higher in mercury as compared to adjacent sites in their watersheds. When converted to units of dry weight parts per million, the 250 g normalized trout mercury concentrations of this study range from a low of 0.14 mg kg^{-1} to a high of 0.94 mg kg^{-1}. These data are used in Table 2 for comparison with the invertebrate data, which are reported on a dry weight basis.

Several collections of piscivorous squawfish and adult brown trout were made during the course of the study. Being largely fish eaters, these species feed at a higher trophic level, as compared to mid-sized rainbow trout which feed primarily on a mix of aquatic and terrestrial insects. The piscivorous fish contained significantly higher concentrations of mercury than rainbow trout from the same locations (Table 3). At the Middle Fork Yuba River site near Oregon Creek, squawfish contained 0.41 mg kg^{-1} muscle mercury in same sized fish, as compared to rainbow trout which had 0.19 mg kg^{-1} (both on a wet weight basis). At the Middle Fork American River Site below Oxbow Reservoir, a large (965 g) brown trout was taken which had muscle mercury at 0.37 mg kg^{-1}, while a comprehensive sample of rainbow trout from the same river stretch had muscle mercury at only 0.05 mg kg^{-1}. The correlation between trophic feeding level and mercury concentration is also apparent in the data from Duncan Creek (Site 52), the South Fork American River at Slab Creek Reservoir (Site 54), and Sites 33 and 34 on the upper section of the South Fork Yuba River (Table 3). At these sites, samples of small (< 250 g) rainbow and brown trout were taken together. At these sizes, the species are both insectivorous. Mercury concentrations were found to be identical at these sites between the two species.

The relationship between muscle mercury and liver mercury was investigated in the first year of the study. The data are presented together with muscle mercury data in Table 3. Generally, the liver mercury concentrations in these fish were very similar to corresponding muscle mercury levels. Mean liver mercury from 77 rainbow and small brown trout was 97.9% of corresponding muscle mercury concentrations, with a standard deviation of 23.5%. We have found, in other research, that liver mercury is frequently 150-200% of muscle mercury in extremely polluted sites, such as Coast Range lakes and reservoirs in the historic mercury mining district of California (Slotton 1991). These liver data, together with the lower absolute tissue mercury concentrations, indicate a relatively more moderate level of mercury bioavailability in the Sierra gold district as compared to the Coast Range mercury mining districts.

Trout stomach contents were analyzed for mercury at a subset of the sampling sites. These data are displayed in Table 2 together with other trophic mercury data for each site. The food item mercury data was generally reflective of corresponding stream invertebrate mercury levels. In the several cases where food item mercury was considerably lower than corresponding stream invertebrate mercury, it was noted that terrestrial insects dominated the stomach contents. The diets of insectivorous rainbow trout and young brown trout naturally demonstrate temporal shifts in the percentage of terrestrial forms, in conjunction with changes in availability.

Stream Invertebrates

Aquatic invertebrates were taken at each of the 57 sites. Approximately 250 separate invertebrate composite samples were collected, identified, processed, and analyzed for mercury in the research reported here. The sites varied considerably in invertebrate diversity and types present. The most consistently available groups were drift feeding caddisfly nymphs of the family Hydropsychidae (omnivores), stonefly nymphs of the family Perlidae (small-item predators), and hellgrammites of the family Corydalidae (large-item predators). The lowest trophic feeding level of stream invertebrates taken, herbivorous species, were represented by a variety of families, with Pteronarcyid stoneflies being the most frequently taken. A variety of mayfly species represented this trophic level at a number of sites. Additional herbivores included large beetle larvae of the family Ptilodactylidae. The omnivore/drift collector feeding level was represented exclusively by Hydropsychid caddis nymphs, which were widespread throughout much of the region. The invertebrate small-item predator trophic level included Rhyacophyllid caddis nymphs, Perlodid stoneflies, and damselfly nymphs in addition to the Perlid stoneflies which were most generally available. In addition to Corydalid hellgrammite nymphs, the larger-item invertebrate predator trophic level also included large predaceous dipteran larvae of the family Tipulidae and Gomphid dragonfly nymphs.

The invertebrate mercury data are presented in Table 2 and Figures 5-8. The table includes data from each of the samples, while averaging techniques were utilized to derive single trophic level values in the map figures. The averaging methods used are described above in the Methods section. Mercury was detected at ≥ 0.01 mg kg^{-1} (ppm) in all invertebrate samples taken throughout the Sierra Nevada gold country. Inter-site mercury differences were generally consistent among all invertebrate (and trout) trophic levels, with low mercury sites demonstrating low biotic Hg levels throughout the food web and sites with high biotic Hg in one group typically having elevated Hg levels in all co-occurring organisms.

Similar to the trout results, notably elevated mercury in stream invertebrates was found at sites along the Middle and South Forks of the Yuba River, and the Middle Fork of the Feather

River. Also as found for trout, invertebrates from the mid section of the Middle Fork Feather River (Site 11), the North Fork of the Middle Fork of the American River (Site 49) and Spanish Creek (Site 7), a tributary to the North Fork Feather River, were relatively higher in mercury as compared to adjacent sites in their watersheds. Relatively low mercury concentrations ($\leq$ 0.15 mg kg^{-1}, dry weight) were found in all trophic levels of invertebrates from most tributaries of the Feather and American rivers, as well as upstream of the major mining activity along the Middle and South Forks of the Yuba River, similar to co-occurring trout.

Invertebrates were also sampled exclusively at 36 sites where trout were not present in sufficient quantities for adequate collections. These invertebrate-only collections identified a number of additional notably elevated mercury streams, including sites throughout the Bear River watershed mining region (Sites 38-42), the Cosumnes River (Sites 56 and 57), and Deer Creek (Site 35). Other invertebrate-only collections indicated relatively low mercury bioavailability at sites where trout were not present or readily collectable, including the Feather River downstream of Lake Oroville (Site 1), several additional tributaries of the Feather River (Sites 8, 9, 14, 15), the lower American River below Folsom Lake (Sites 45 and 46), the South Fork of the American River (sites 53-55), the Rubicon River (site 50), and the Bear River below Camp Far West Reservoir (site 37). Similar to the reduced mercury results found in fish above the gold mining stretches of the forks of the Yuba River, benthic invertebrate samples of all types from the relatively pristine headwaters sample on the Bear River (Site 44) were far lower in mercury concentration than corresponding samples taken from within and below the major mining elevations (Sites 38-42).

Notably lower invertebrate mercury concentrations were found below many of the foothill reservoirs, as compared to concentrations in similar biota upstream. Specifically, the invertebrates below New Bullard's Bar Reservoir (station 18) were considerably lower in mercury than those collected upstream of the reservoir on the North Fork of the Yuba River (station 20). Hydropsychid net caddis nymphs were 0.08 ppm in their dry weight mercury concentration below the dam, as compared to 0.24 ppm upstream of the reservoir. Perlid stoneflies were 0.11 ppm below, 0.25 ppm above, and Corydalid hellgrammites were 0.33 below vs 0.50 above. Similarly, the invertebrates collected below Englebright Reservoir (station 16) were consistently far lower in mercury than samples collected upstream of the reservoir on the Middle and South Forks of the Yuba River (sites 22, 24, 25, 28-32). On the Bear River, Hydropsychid net caddis larvae ranged from 0.21 to 0.46 ppm Hg (mean = 0.32 ppm) at sites in the mining region above Camp Far West Reservoir (sites 38-42), as compared to 0.17 ppm in extensive, replicate collections from below the dam.

Collections from the Feather River valley site below Lake Oroville (Site 1) and the American River below Folsom Lake (Sites 45 and 46) were similar to samples taken upstream in these relatively low mercury watersheds. Deer Creek was unique in demonstrating significantly higher biotic mercury accumulation below a reservoir (Lake Wildwood) as compared to above (Site 35 vs 36). While both sites were relatively elevated, the higher levels found below Lake Wildwood may result from historic downstream movement of gold mining mercury in this small drainage. The lack of significant modern barriers to downstream mercury migration may be of particular concern on the Cosumnes River (Sites 56 and 57), where the very highest levels of biotic mercury accumulation were observed.

Trophic level relationships to mercury accumulation

A pattern of increasing mercury concentrations in progressively higher trophic levels was found at the majority of sites (Figure 3, Table 2). In Figures 11 and 12 we summarize the food-chain mercury data from 19 sites where trout were sampled, normalized to 250 g rainbow trout muscle concentrations at each of the sites. In Figure 11, the normalized invertebrate data are plotted with 95% confidence intervals for trophic guilds vs trout, and in Figure 12 the dominant single family or genus of each guild is used. The means and confidence intervals are similar with either analysis.

A relatively predictable pattern results, with the highest trophic level stream invertebrates having mercury concentrations approximately half those seen in normalized 250 g trout from the same sites. Among the invertebrates, herbivorous species as a group consistently had the lowest mercury concentrations (averaging 14% of those found in co-existing trout). Low mercury levels in herbivore species was not a function of age and, thus, time of exposure. Similar low concentrations were found in Pteronarcyid stoneflies up to three years old, as well as in annual mayflies. Predaceous invertebrates accumulated considerably higher concentrations. Relatively small predators such as nymphs of Perlid stoneflies, Rhyacophyllid caddisflies, and damselflies had mercury concentrations averaging 38% of the concentrations in corresponding normalized trout muscle, while the largest invertebrate predators, characterized by the large-jawed hellgrammites, averaged 47% of trout concentrations. Hydropsychid caddis nymphs, which were an important component of the invertebrate biomass at many of the sites, averaged 31% of corresponding trout in their mercury levels. This was lower than that of the larger invertebrate predators but considerably higher than the mercury concentrations seen in herbivores, suggesting that these nymphs, which feed by capturing drift in their nets, consume primarily other invertebrates rather than algal material. We believe that relative mercury concentrations in aquatic species may offer a useful tool for determining relative, time-integrated trophic feeding level.

In Figures 13-19, mercury concentrations in different trophic categories and types of invertebrates are plotted against corresponding trout mercury to determine relative correlations.

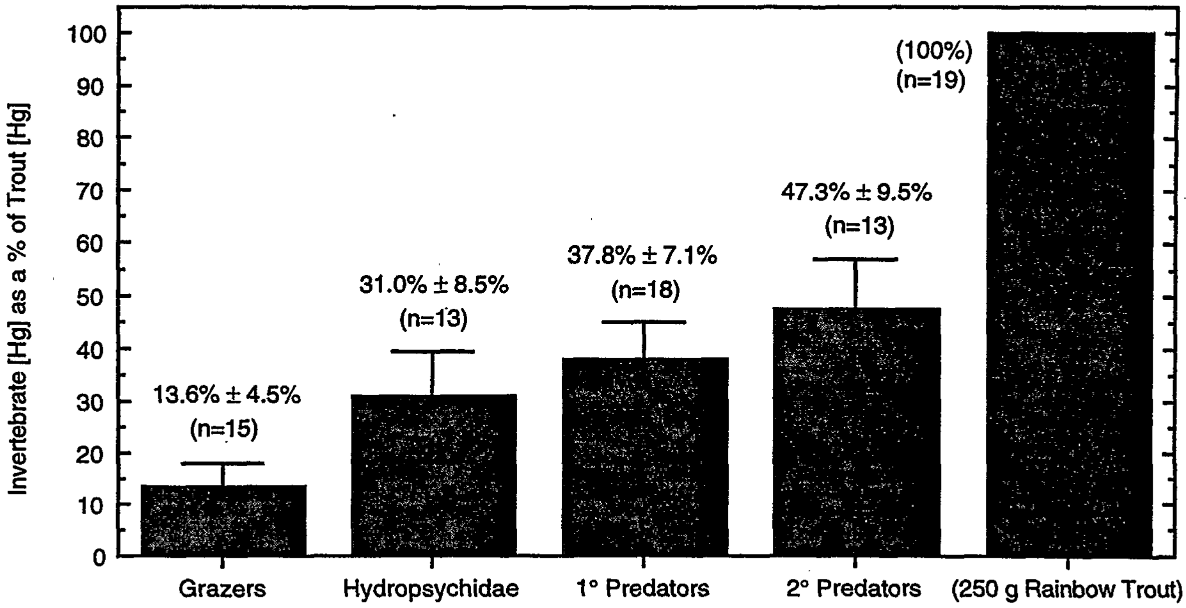


Fig. 11. Mercury in Invertebrate Trophic Groups--As a Proportion of Corresponding Fish Mercury, Among Sites With Sampled Fish

In units of dry wt parts per million Hg, together with 95% confidence intervals

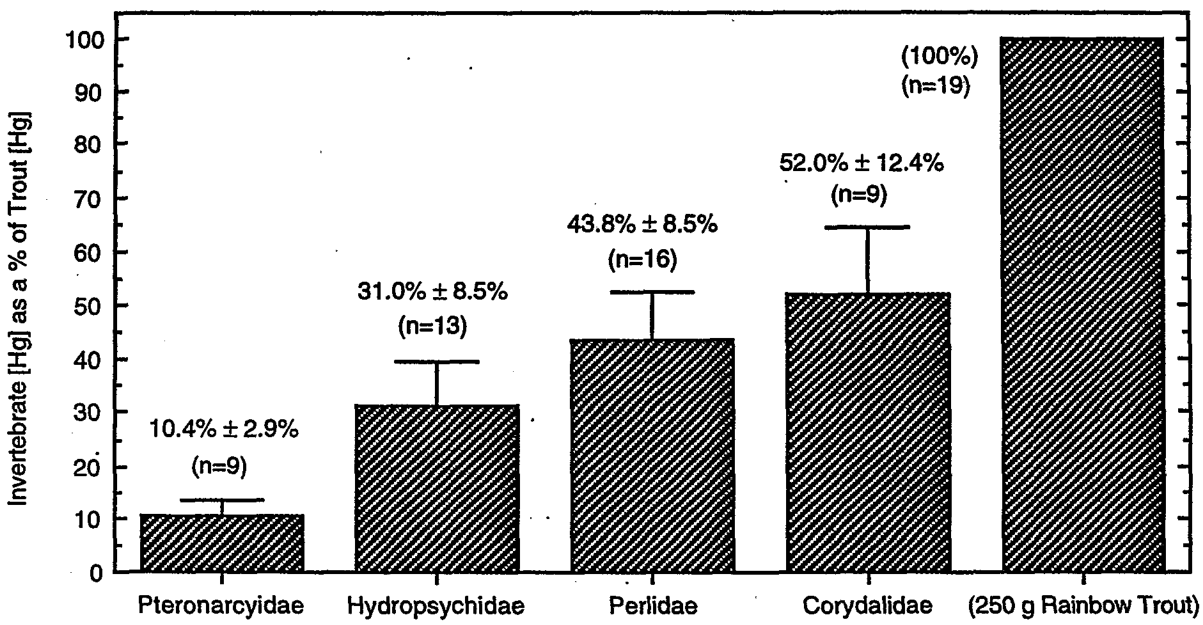


Fig. 12. Mercury in Individual Invertebrate Families--As a Proportion of Corresponding Fish Mercury, Among Sites With Sampled Fish

In units of dry wt parts per million Hg, together with 95% confidence intervals

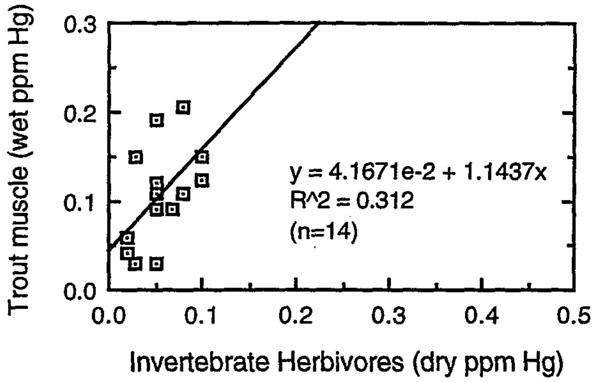


Fig. 13. Invertebrate Herbivores vs Trout

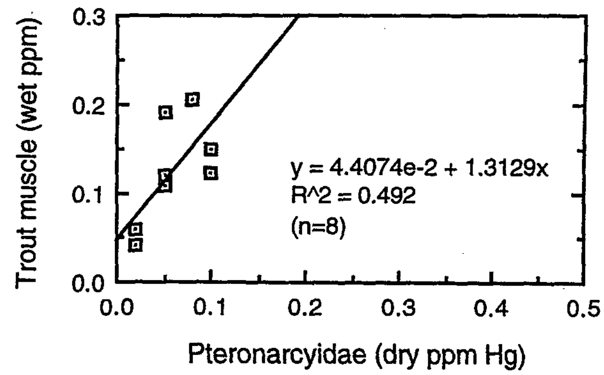


Fig. 14. Pteronarcyidae (Giant Herbivorous Stoneflies) vs Trout

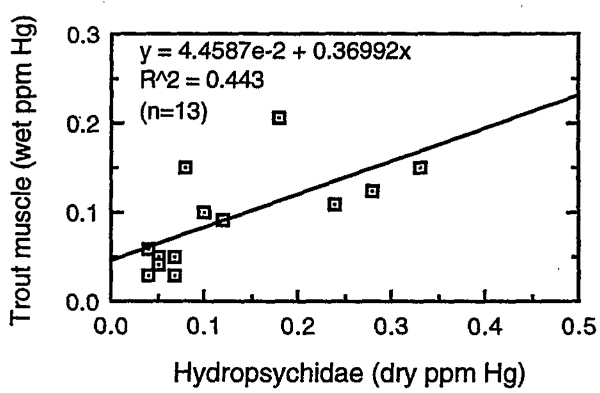


Fig. 15. Hydropsychidae (Net Collector Caddis) vs Trout

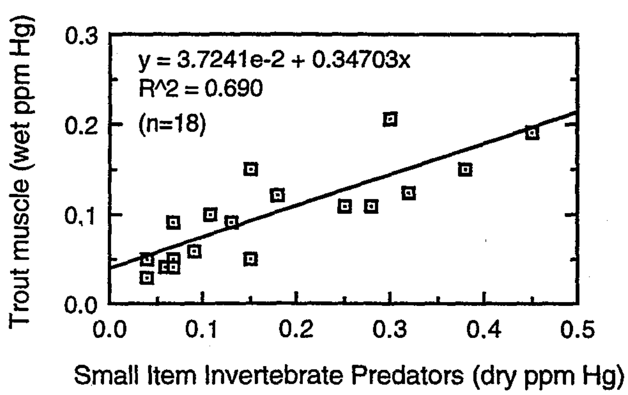


Fig. 16. Small Item Invertebrate Predators (Perlid Stoneflies, etc.) vs Trout

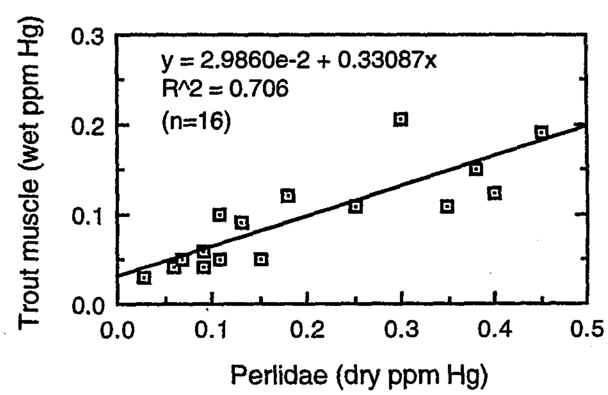


Fig. 17. Perlid Stoneflies vs Trout

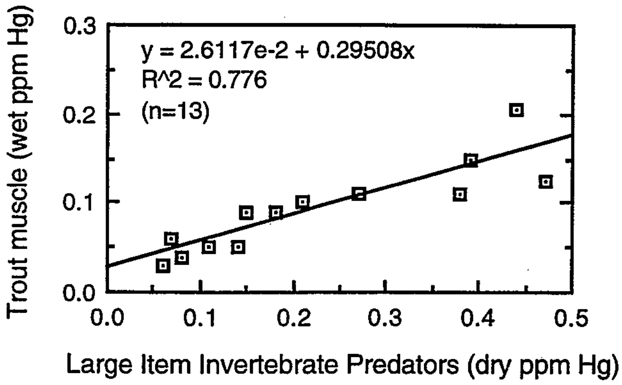


Fig. 18. Large Item Invertebrate Predators (Hellgrammites, etc.) vs Trout

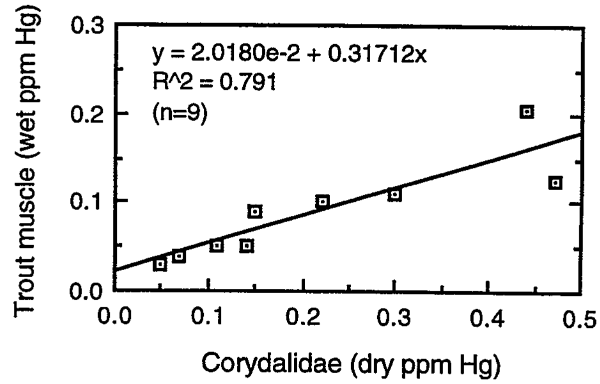


Fig. 19. Corydalid Hellgrammites vs Trout

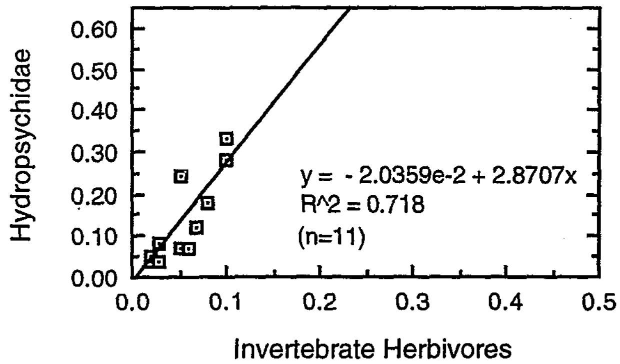


Fig. 20. Invertebrate Herbivores vs Hydropsychidae (Net Collector Caddis)

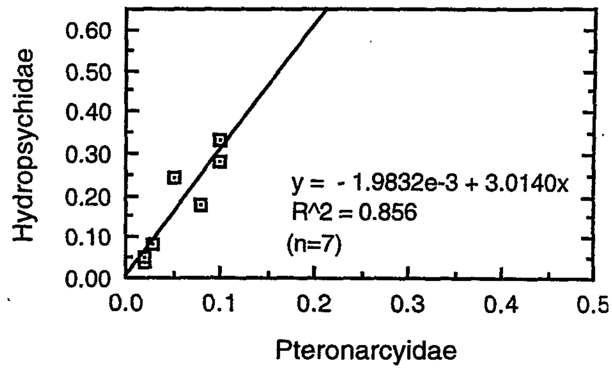


Fig. 21. Pteronarcyidae (Giant Herbivorous Stoneflies) vs Hydropsychidae (Net Collector Caddis

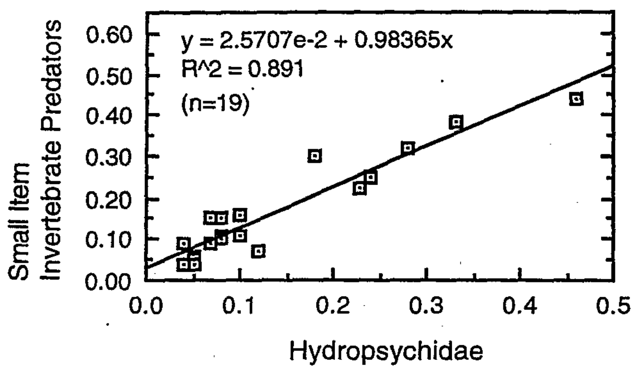


Fig. 22. Hydropsychidae (Net Collector Caddis) vs Small Item Predators (Perlid Stoneflies, etc.)

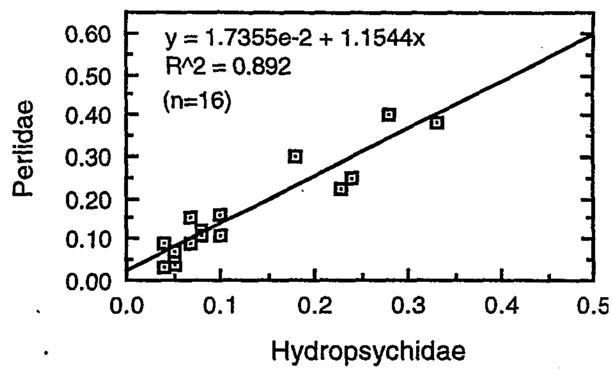


Fig. 23. Hydropsychidae (Net Collector Caddis) vs Perlidae (Predaceous Golden Stoneflies)

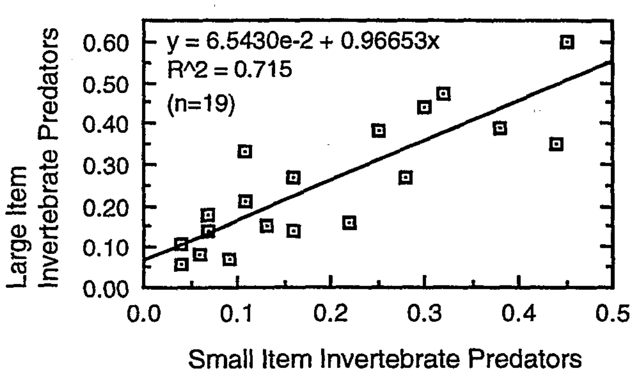


Fig. 24. Invertebrate Small Item Predators (Perlid Stoneflies, etc.) vs Large Item Predators (Hellgrammites, etc.)

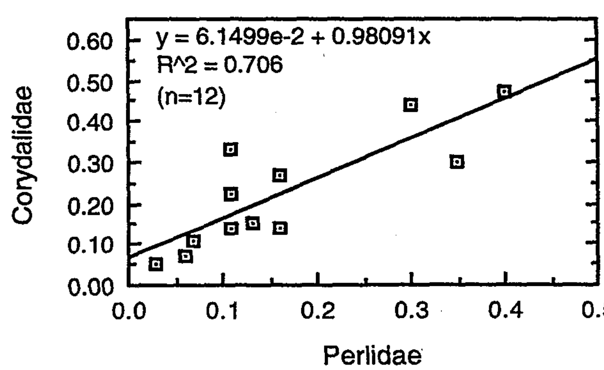


Fig. 25. Perlid Stoneflies vs Corydalid Hellgrammites

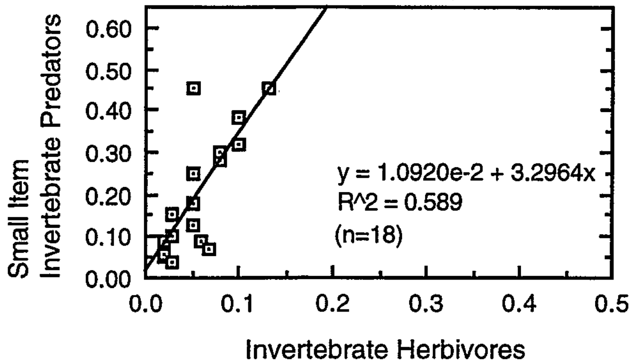


Fig. 26. Invertebrate Herbivores vs Small Item Predators (Perlid Stoneflies, etc.)

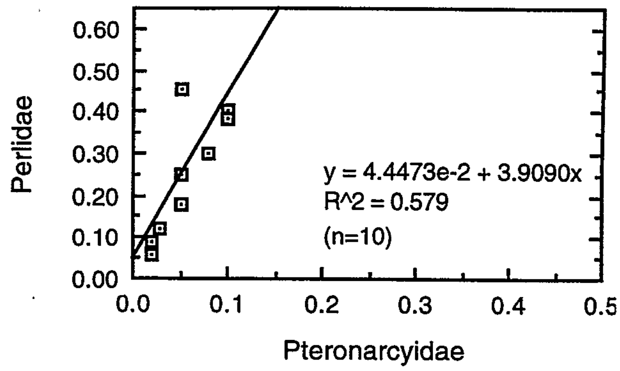


Fig. 27. Pteronarcyidae (Giant Herbivorous Stoneflies) vs Perlidae (Predaceous Golden Stoneflies)

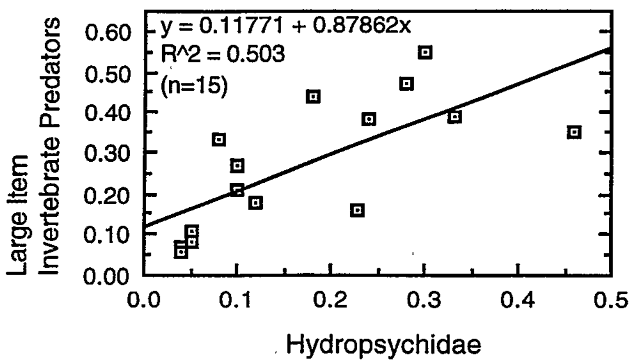


Fig. 28. Hydropsychidae (Net Collector Caddis) vs Large Item Invertebrate Predators (Hellgrammites, etc.)

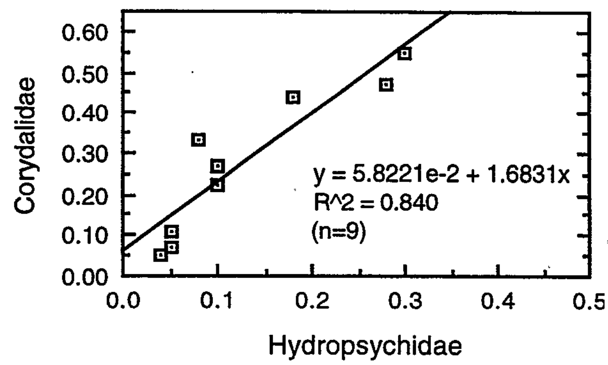


Fig. 29. Hydropsychidae (Net Collector Caddis) vs Corydalidae (Hellgrammites)

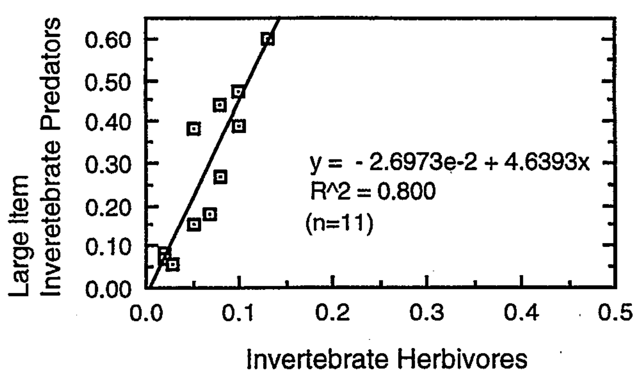


Fig. 30. Invertebrate Herbivores vs Large Item Predators (Hellgrammites, etc.)

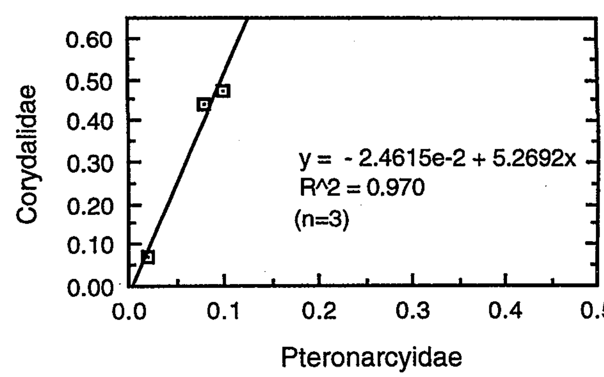


Fig. 31. Pteronarcyidae (Giant Herbivorous Stoneflies) vs Corydalidae (Hellgrammites)

Interestingly, the R^2 correlation coefficients between invertebrates and trout taken from the same sites increased steadily with increasing invertebrate trophic feeding level. Herbivores, as a group, demonstrated the weakest correlation with corresponding trout ($R^2 = 0.31$). Hydropsychid caddis nymphs had a stronger correlation ($R^2 = 0.44$). Small predaceous invertebrates such as Perlid stoneflies had considerably tighter correlations with trout ($R^2 = 0.69$), while the highest trophic level invertebrates, characterized by Corydalid hellgrammites, demonstrated the strongest correlations with corresponding trout ($R^2 = 0.78$). Correlations between individual invertebrate family or genus and trout (figures 11, 14, and 16) were generally not significantly stronger than those using grouped trophic guild members, though this may be partially a function of lower sample size for particular invertebrates.

In Figures 20-31, correlations in mercury concentration between invertebrates are plotted, first between adjacent trophic feeding levels (Figures 20-25) and finally between more distantly separated groups (Figures 26-31). As a set, these inter-invertebrate correlations were all quite high. R^2 correlation coefficients of 0.72-0.98 were found between adjacent trophic levels (Figures 20-25) and coefficients of 0.50-0.97 were found between non-adjacent but co-occurring trophic levels (Figures 26-31).

Biotic time series data

A series of 5 separate collections were made throughout 1995 and early 1996 at 3 index stations, to address the question of potential seasonal shifts in biotic mercury accumulation. Data are presented in Table 4. These sites corresponded to those also used for the intensive temporal series of water collections by Larry Walker and Associates, and were all adjacent to Englebright Reservoir. One site was located below the reservoir on the Lower Yuba River (Site 16), while the other two were situated immediately above the reservoir along the two major inflowing tributaries. Site 17 was an index station located just below the Colgate powerhouse on the Middle Fork Yuba River. The Colgate powerhouse is where the majority of flow from the North Fork Yuba River is diverted into the Middle Fork, piped from the bottom of New Bullards Bar Reservoir. The North Fork flow typically dominates the total flow at this point, though releases can be erratic. The final index station (Site 28) was located along the South Fork Yuba River at Bridgeport, just above Englebright Reservoir.

Sampling for this temporal series of invertebrate bioindicator collections occurred on April 24, June 30, August 15, and November 16 in 1995, and February 16, 1996. Composite collections of 3-7 different types of benthic invertebrates were made on each of the five dates at the lower Yuba site (16) and the site on the South Fork Yuba (28). However, at Site 17 below the Colgate powerhouse, only Hydropsychid caddisfly larvae were present on the August sampling

Table 4. Biota Mercury Data For Time Series Samplings at Above/Below Englebright Reservoir Index Stations

identification	trophic level	Hg (dry wt ppm)
16. Lower Yuba River at UC field station --1993 (12/16/93)		
Ephemerellidae (mayfly)	herbivore	**0.07**
Hydropsychidae (net caddis)	drift feeder	**0.12**
Perlodidae (stonefly)	small predator	**0.07**
Tipulidae (cranefly)	large predator	**0.18**
Mean 250 g Trout (dry ppm)	*(insect predator)*	***0.42***
16*. Lower Yuba River at UC field station. (4/24/95)		
Mixed Mayflies	herbivore	**0.050**
Hydropsychidae	drift feeder	**0.140**
Perlodidae-sm	small predator	**0.113**
Perlidae-giant	small predator	**0.132**
Tipulidae-lg	large predator	**0.490**
16**. Lower Yuba River at UC field station. (6/30/95)		
Mayflies	herbivore	**0.018**
Hydropsychidae	drift feeder	**0.082**
Perlodidae-tiny	Tiny Stoneflies	*(<0.01)*
Hellgrammite	large predator	**0.231**
16. Lower Yuba River at UC field station. (8/15/95)***		
Mayflies	herbivore	**0.080**
Hydropsychidae-sm/med	drift feeder	**0.122**
Hydropsychidae-lg	drift feeder	**0.129**
Beetle larvae	small predator	**0.082**
Perlodidae-sm/med	small predator	**0.095**
Perlidae-Callineuria-lg	small predator	**0.108**
Hellgrammite-med	large predator	**0.273**

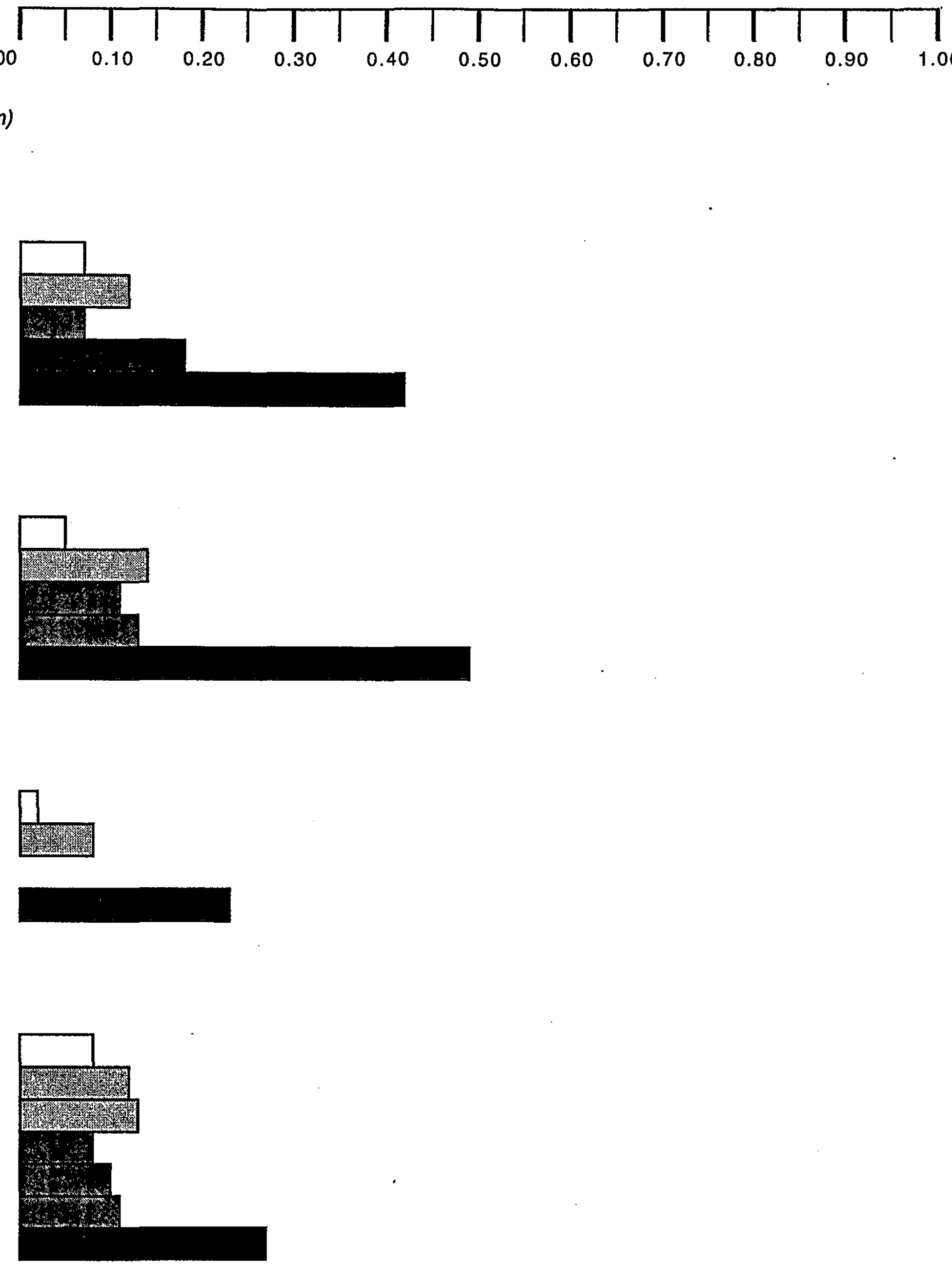
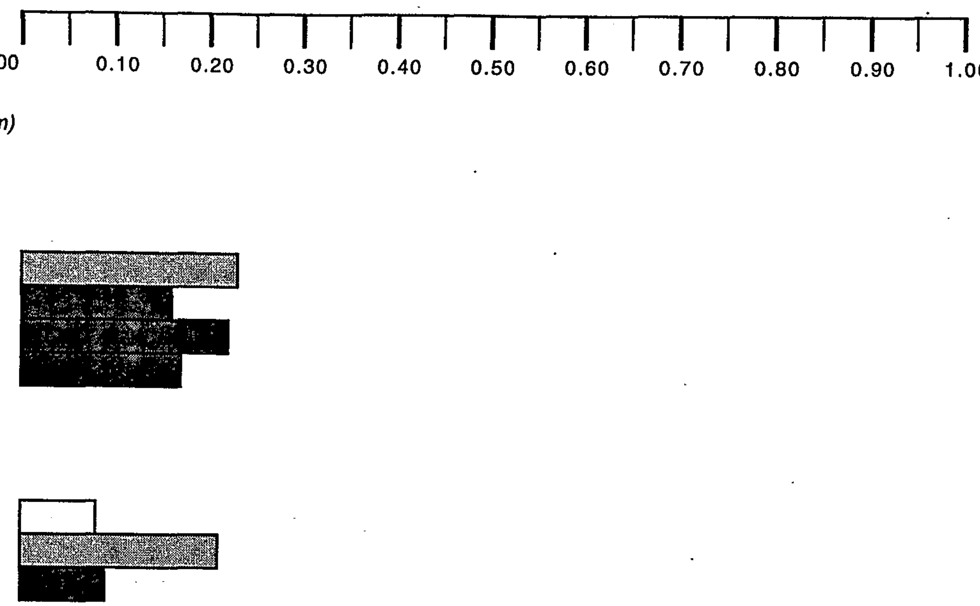
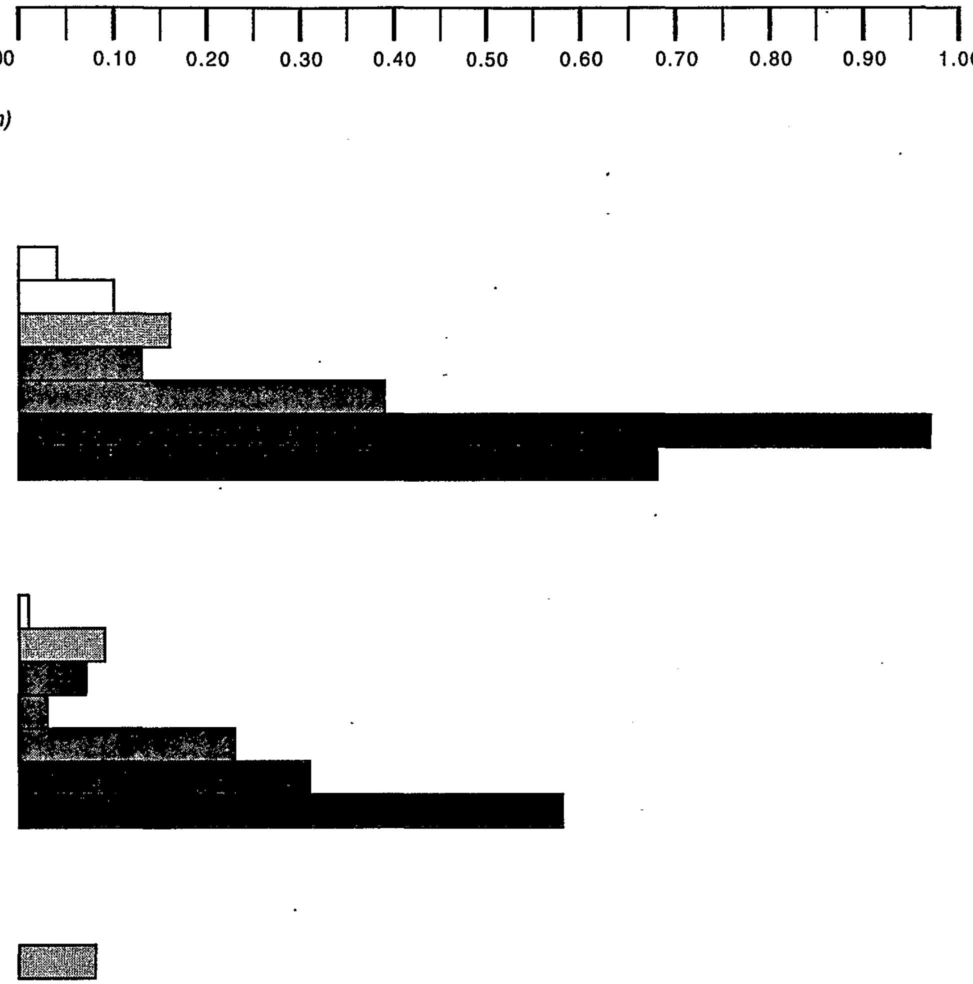


Table 4. (continued)



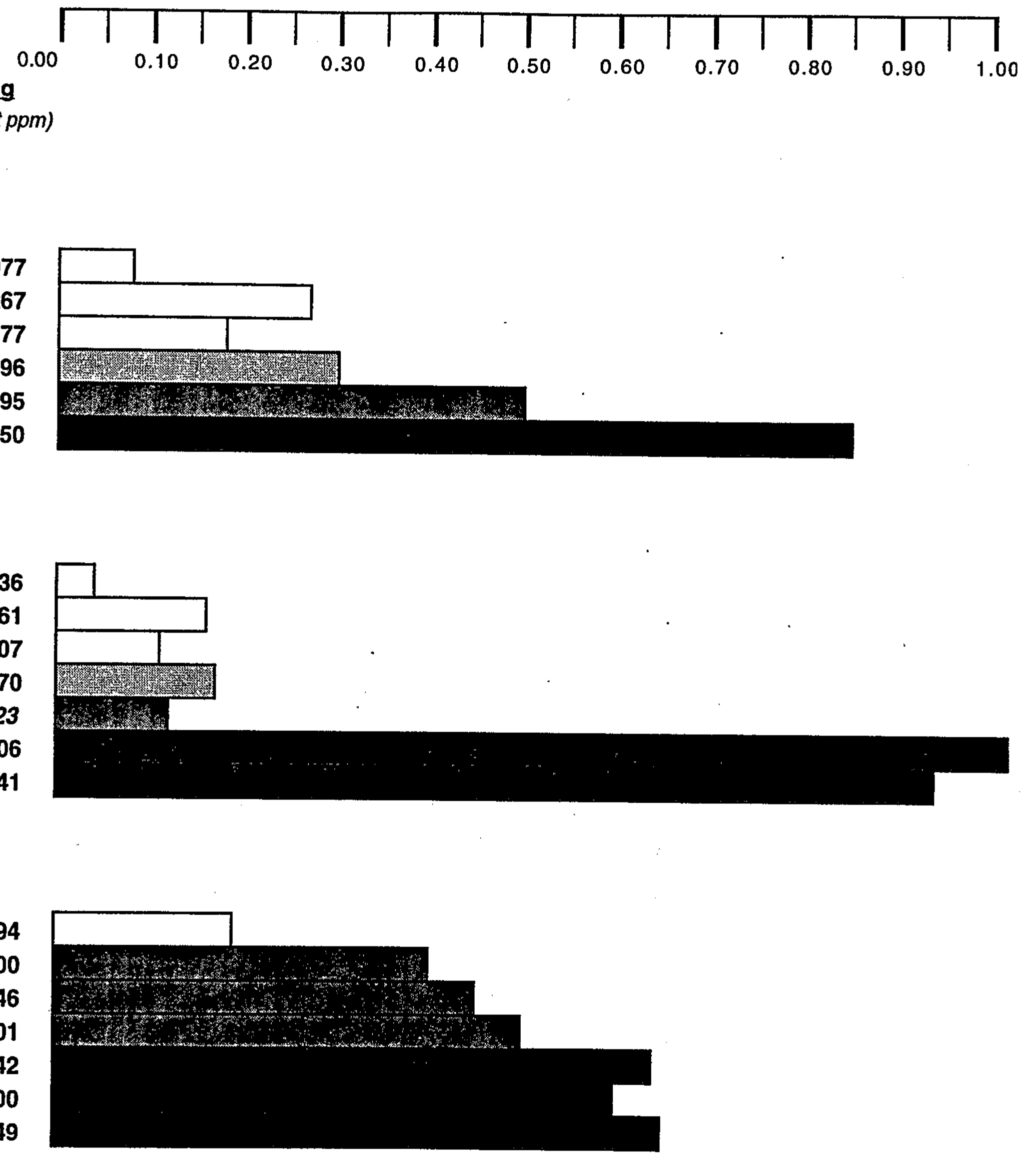
identification	trophic level	Hg (dry wt ppm)
16*. Lower Yuba River at UC field station. (11/16/95)***		
Hydropsychidae	drift feeder	**0.225**
Perlodidae-med/Lg	small predator	**0.155**
Perlidae-Hesperoperla-med/Lg	small predator	**0.218**
Perlidae-Hesperoperla-giant-2 yr	small predator	**0.169**
16**. Lower Yuba River at UC field station. (2/16/96)***		
Mixed Mayflies	herbivore	**0.080**
Hydropsychidae-med/lg	drift feeder	**0.211**
Perlodidae	small predator	**0.094**

Table 4. (continued)



identification	trophic level	Hg (dry wt ppm)
17. N Fk / M Fk Yuba River below Colgate inflow. (4/24/95)		
Pteronarcyidae-sm	leaf shredder	**0.040**
Mayflies	herbivore	**0.099**
Hydropsychidae	drift feeder	**0.163**
Perlodidae-sm	small predator	**0.130**
Perlidae-lg	small predator	**0.390**
Hellgrammites-lg	large predator	**0.970**
Hellgrammites-giant	large predator	**0.680**
17*. N Fk / M Fk Yuba River below Colgate inflow. (6/30/95)		
Mayflies	herbivore	**0.006**
Hydropsychidae	drift feeder	**0.094**
Perlidae-sm	small predator	**0.073**
Perlidae-lg	small predator	**0.031**
Perlidae-giant	small predator	**0.224**
Hellgrammites-sm	large predator	**0.314**
Hellgrammites-lg	large predator	**0.577**
17**. N Fk / M Fk Yuba River below Colgate inflow. (8/15/95)		
Hydropsychidae	drift feeder	**0.078**

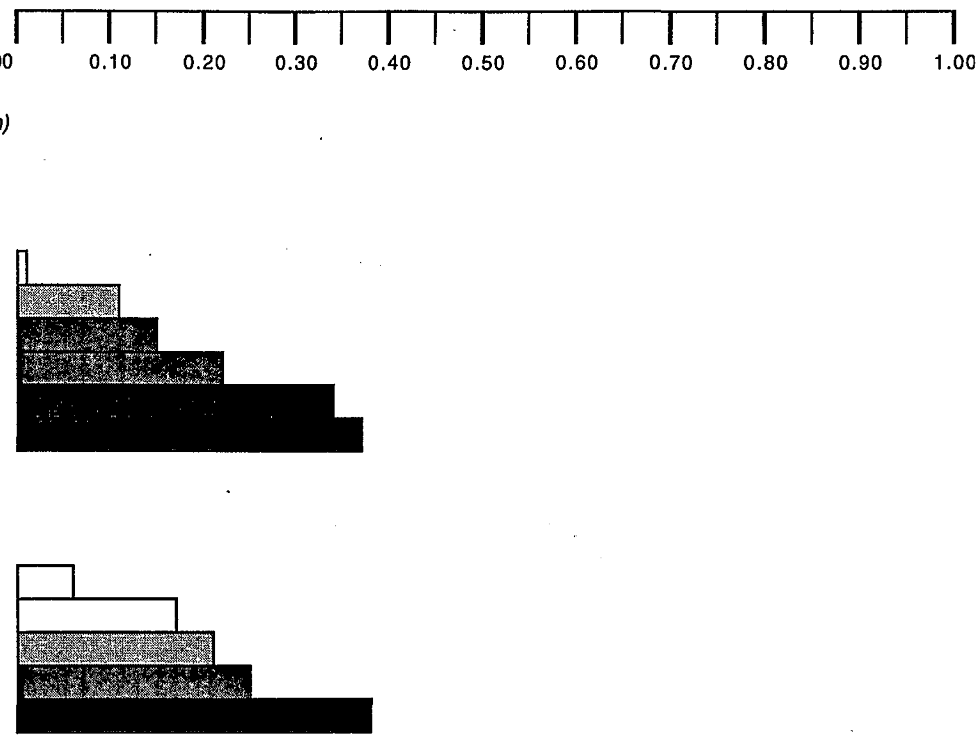
Table 4. (continued)



identification	trophic level	Hg (dry wt ppm)
28. South Fork Yuba River at Bridgeport. (4/24/95)		
Pteronarcyidae-sm	leaf shredder	**0.077**
Mayflies	herbivore	**0.267**
Ptilodactylidae	herbivore	**0.177**
Hydropsychidae	drift feeder	**0.296**
Perlidae	small predator	**0.495**
Hellgrammites-lg	large predator	**0.850**
28*. South Fork Yuba River at Bridgeport. (6/30/95)		
Pteronarcyidae	leaf shredder	**0.036**
Mayflies	herbivore	**0.161**
Ptilodactylidae	herbivore	**0.107**
Hydropsychidae	drift feeder	**0.170**
Perlodidae-sm	Sm. Stoneflies	***0.123***
Hellgrammites-lg	large predator	**1.306**
Hellgrammites-giant	large predator	**0.941**
28**. South Fork Yuba River at Bridgeport. (8/15/95)		
Mixed Grazers	herbivore	**0.194**
Perlidae-sm/med	small predator	**0.400**
Perlidae-Heperoperla-med/lg	small predator	**0.446**
Perlidae-Heperoperla-lg/giant	small predator	**0.501**
Hellgrammites-sm/med	large predator	**0.642**
Hellgrammites-med/lg	large predator	**0.600**
Hellgrammites-lg/giant	large predator	**0.649**

Table 4. (continued)

identification	trophic level	Hg (dry wt ppm)
28. South Fork Yuba River at Bridgeport. (11/16/95)***		
Pteronarcyidae	leaf shredder	**0.007**
Hydropsychidae	drift feeder	**0.113**
Perlodidae-med/Lg	small predator	**0.149**
Perlidae-Lg	small predator	**0.216**
Hellgrammites-sm	large predator	**0.344**
Hellgrammites-sm	large predator	**0.369**
28*. South Fork Yuba River at Bridgeport. (2/16/96)***		
Pteronarcyidae-sm/med	leaf shredder	**0.056**
Mixed Mayflies	herbivore	**0.172**
Hydropsychidae-med/lg	drift feeder	**0.213**
Perlidae	small predator	**0.248**
Hellgrammite-giant	large predator	**0.375**



date and, on subsequent samplings, the site was essentially barren. We attributed this to the unnatural mid-summer releases of very cold North Fork Yuba water from the base of New Bullards Bar Reservoir and the erratic flow regime, which varied between zero and very high flows from this cold source. When the flows from New Bullards Bar Reservoir were high, the water beneath the Colgate powerhouse was very swift and cold; when that source was shut down, the flow returned to that of the relatively warm, low flow Middle Fork Yuba. Our unsuccessful collection attempts (despite considerable sampling effort) from mid-summer through the winter indicate that the conditions at this site were too erratic to maintain a diverse community of typical benthic invertebrate fauna.

Comparing the entire data sets for each site, it is apparent that the below-reservoir site on the Yuba River (Site 16) was consistent in demonstrating significantly lower levels of mercury accumulation, throughout the trophic levels, than the sites above the reservoir. Because of a shift in species present at this site over time, it is difficult to draw conclusions with regard to potential seasonal changes in mercury accumulation here. Hydropsychid caddisfly larvae, which were present in all Lower Yuba collections, suggest a possible increase in mercury accumulation at the Lower Yuba site in the fall and winter, as integrated by the November 1995 and February 1996 samples (0.21-0.23 ppm Hg Nov-Feb vs 0.08-0.14 ppm Hg Apr-Aug). However, other sampled species did not follow any particular trend. Except for a single somewhat anomalous data point for Tipulid dipteran larvae in June 1995 (0.49 ppm), all Lower Yuba benthic invertebrate indicator samples contained $\leq$ 0.27 ppm mercury.

In contrast, composite samples of benthic invertebrates from the inflowing tributaries to the reservoir consistently demonstrated significantly elevated levels of mercury accumulation in most trophic levels. All samples of second order predatory invertebrates from these sites were found to contain more than 0.30 ppm mercury, with individual composites ranging to over 1.30 ppm. Comparative trout were not present at the reservoir inflow sites, though trout collected below the reservoir were far lower in mercury than were trout taken at sites where they were present further up the Forks of the Yuba within the historic gold mining region.

After seeing firsthand the large variation in flow conditions, we hesitate to form conclusions on potential temporal trends for the North Fork/Middle Fork Yuba reservoir inflow site below the Colgate powerhouse (17). Diverse samples were only available for the first two collections (April and June), during which time mercury levels appeared to drop fairly uniformly. However, because of the unique conditions at this site brought on by flow manipulations, it is unclear whether this apparent trend might be a function of different proportions of Middle Fork Yuba water being present at different times or if the invertebrates taken below the powerhouse on one or both of the significant collections might actually represent drift from the Middle Fork.

The samples from the South Fork inflow, however, indicate an interesting trend of apparent reduced mercury accumulation in fall and winter as compared to earlier collections. This was particularly the case for the predatory trophic levels. Corydalid hellgrammite composites from April through August averaged a very high 0.83 ppm mercury, as compared to 0.36 ppm in November and February. Perlid stoneflies averaged 0.46 ppm in April-August collections, as compared to 0.23 ppm in November and February. This indicates that, at this representative site and this sampling year, less bioavailable mercury moved into the food web later in the year as compared to earlier. This could be a function of changes in bulk mercury presence, changes in mercury methylation within the stream, or a combination of the two.

One conclusion to be drawn from the temporal collections is that comparative sampling of benthic invertebrate indicator samples between sites should be done within a relatively similar time frame, as levels can change fairly significantly across periods on the order of 6 months. Fortunately, the great majority of collections made for the survey work occurred between the months of September and December in each of the years.

Methyl mercury split data

Splits of a subset of the total samples were sent to Frontier Geosciences Laboratory in Washington state for analysis of methyl mercury. Results from split and duplicate samples indicated that this particular assay was limited in accuracy to a range of approximately ± 25%, as compared to the total mercury analysis which has a variability closer to ± 10%. Because of the fairly high level of analytical variation, temporal trends in methyl mercury content cannot be ascertained. Methyl fractions varied fairly erratically and within a range generally less than or equal to the analytical range of variation. However, the general methyl mercury results provide some useful information.

Reduced methyl mercury data are presented in Table 5, together with corresponding total mercury results and the calculated methyl mercury percentage for each sample. Except for a single lower point, all of the data that passed QA/QC controls varied somewhat erratically in the general range of 55-100% methyl mercury. In approximately 10% of the samples that were near the respective limits of detection, impossible results of 110-500+% methyl mercury were obtained, presumably through analytical error at the bottom end of the scale. These data are not shown in the table.

Pteronarcyid stoneflies, which are shredders of primarily terrestrial leaf fall, had methyl mercury percentages which varied between 64% and 100%, with a mean of 76.2% ± 14.5%. Herbivorous mayflies ranged from 60% to 79% methyl mercury, with a mean of 69.4% ± 12.8%. Hydropsychid caddisfly larvae ranged between 36% and 94%, with a mean value of 68.8% ±

Table 5. Methyl Mercury / Total Mercury Split Data (dry weight ppm Hg)

ENGLEBRIGHT SERIES

	Mayflies			Pteronarcyids			Hydropsyche			Perlodids			Perlids			Hellgrammites		
	MeHg	THg	%	MeHg	THg	%	MeHg	THg	%	MeHg	THg	%	MeHg	THg	%	MeHg	THg	%
4/24/95																		
Lower Yuba	.032	.054	60.3%				.050	.141	35.5%	.085	.113	75.4%						
Colgate							.106	.163	65.0%							0.821	0.971	84.6%
S Fk Yuba				.051	.077	66.0%	.172	.296	58.0%				.442	.495	89.2%	0.611	0.848	72.0%
6/30/95																		
Lower Yuba							.077	.082	94.2%									
Colgate							.070	.094	74.5%									
S Fk Yuba																1.096	1.306	83.9%
8/15/95																		
Lower Yuba	.063	.080	78.5%				.118	.129	91.9%							0.190	0.273	69.6%
Colgate							.052	.078	66.4%									
S Fk Yuba																0.346	0.600	57.6%
11/16/95																		
Lower Yuba							.144	.225	63.8%	.154	.155	99.2%	.189	.218	86.6%			
Colgate																		
S Fk Yuba										.110	.149	73.9%	.192	.216	88.5%	0.336	0.369	91.1%
M Fk Yuba				.114	.115	99.6%	.128	.204	62.8%	.177	.177	100.4%	.239	.246	97.4%	0.311	0.411	75.6%

Table 5. (continued)

INTER-ANNUAL SERIES (Middle Fk Yuba at Tyler Foote Crossing)

	Mayflies			Pteronarcyids			Hydropsyche			Perlodids			Perlids			Hellgrammites		
	MeHg	THg	%	MeHg	THg	%	MeHg	THg	%	MeHg	THg	%	MeHg	THg	%	MeHg	THg	%
Oct-93				.066	.103	63.6%							.270	.325	82.9%			
Oct-94				.177	.220	80.3%	.308	.543	56.7%				.806	.797	101.2%	0.415	0.593	69.9%
Oct-95				.043	.060	71.7%	.125	.222	56.4%				.241	.244	99.0%	0.187	0.215	87.1%

ABOVE/BELOW CAMP FAR WEST RESERVOIR

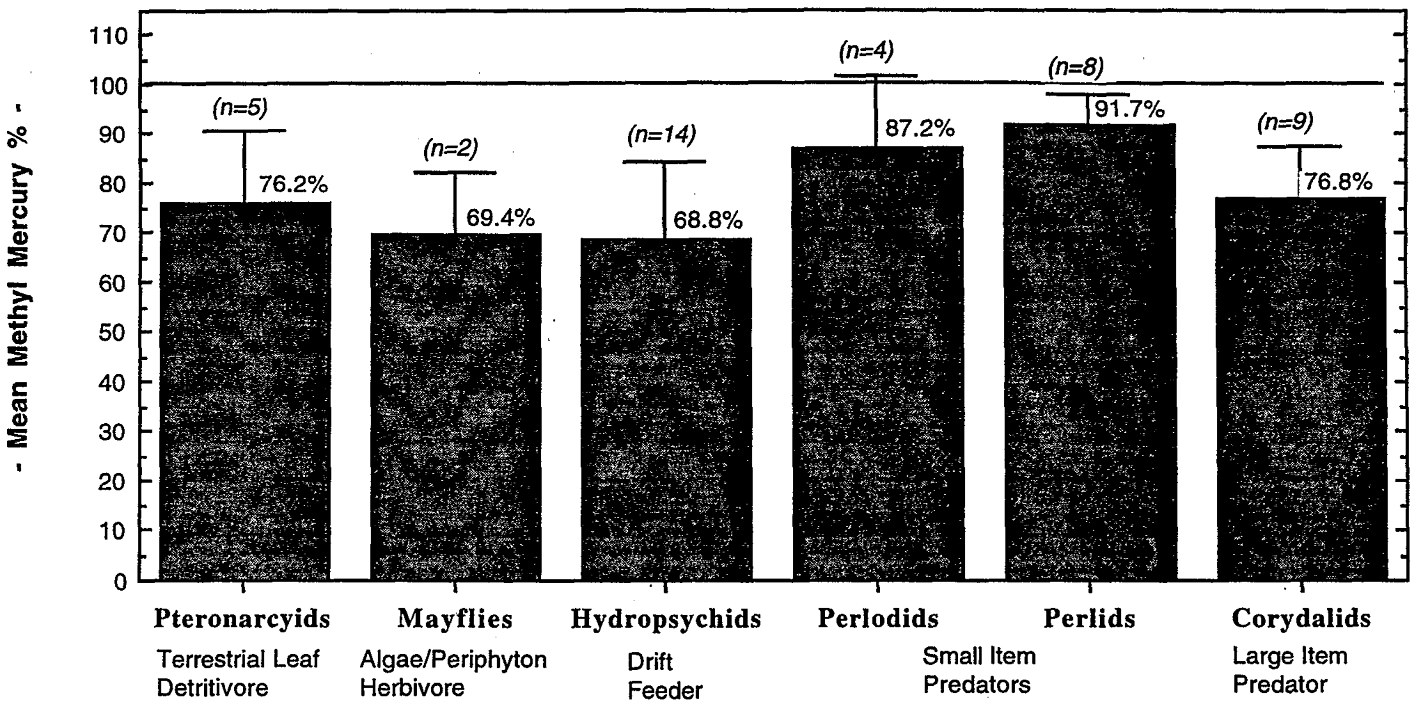
	Mayflies			Pteronarcyids			Hydropsyche			Perlodids			Perlids			Hellgrammites		
	MeHg	THg	%	MeHg	THg	%	MeHg	THg	%	MeHg	THg	%	MeHg	THg	%	MeHg	THg	%
Bear R, Hwy 49							.216	.286	75.5%									
Below Camp FW							.138	.162	85.2%									

LARGE VALLEY RIVER

	Mayflies			Pteronarcyids			Hydropsyche			Perlodids			Perlids			Hellgrammites		
	MeHg	THg	%	MeHg	THg	%	MeHg	THg	%	MeHg	THg	%	MeHg	THg	%	MeHg	THg	%
Lower Feather							.060	.078	77.1%									

Fig. 32. Mean Methyl Mercury Percentages (Of Total Mercury) In Major Sierra Nevada Stream Macro-Invertebrates

(multi-individual composite samples x n composite collections with 95% confidence intervals)



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15.7%. Of the 14 Hydropsychid samples, 13 contained ≥ 56% methyl mercury. Small Perlodid stoneflies had methyl mercury percentages of 74-100% (mean = 87.2% ± 14.6%). Perlid stoneflies varied over a relatively narrow range of 83-101% methyl mercury (mean = 91.7% ± 6.6%) and Corydalid hellgrammites varied in methyl mercury fraction between 58% and 91% (mean = 76.8% ± 10.7%). These mean methyl mercury fractions are displayed graphically in Figure 32.

All of the benthic invertebrate trophic levels demonstrated relatively similar methyl mercury fractions of 69% to 92% on average. Methyl mercury accounted for more than 2/3 of the total mercury accumulated by each of these organisms. It is notable that there was no clear pattern of increasing methyl fraction with trophic level, as might be theoretically expected. However, the data clearly indicates the importance of the methyl species of mercury for biotic accumulation, consistent with many other studies in other aquatic habitats.

Mercury in Englebright Reservoir fish

In July 1996, we used an experimental gillnet from a boat to collect a sample of fish from the midsection of Englebright Reservoir, which receives the inflows from all three forks of the Yuba River. We had difficulty obtaining a large sample, but were able to collect at least a single representative of each of five reservoir fish species. Five Sacramento suckers were taken, together with one each hardhead, carp, smallmouth bass, and largemouth bass. The bass were small (11-12 inches, < 1 pound), while individuals of the other sampled species were mid to large sized adults. Data are presented below in Table 6.

This collection was notable for the relatively quite high mercury levels that were found throughout. Mercury in fresh (wet weight) edible filet muscle ranged from 0.41 to 0.89 ppm, with all values being near, at, or above the 0.50 ppm health advisory level. This was particularly significant in that the majority of the sampled fish were of species that are low in the trophic food web and typically demonstrate relatively very low levels of mercury accumulation. Hardhead is a native species that is herbivorous, while carp is an introduced species that feeds primarily on small invertebrates in the bottom sediment (Moyle 1976). The Sacramento sucker is a native species with feeding habits similar to carp. Comparative data from Clear Lake in the Coast Range, which is known to contain extremely elevated concentrations of sediment inorganic mercury, have consistently demonstrated carp muscle mercury to be in the ≤ 0.25 ppm range, even in very large and old individuals (TSMP 1990, 1991, 1992). The finding of significantly higher mercury concentrations accumulating in carp and other low trophic level fish within Englebright Reservoir indicates that the mercury in this Sierra Nevada foothill reservoir is more readily bioavailable to resident fish.

Table 6. Englebright Reservoir Fish Muscle (Filet) Mercury Concentrations (fresh/wet weight ppm Hg, July 1996)

Identification	Weight (g)	Length (mm)	Weight (lbs)	Length (inches)	Muscle Hg (wet wt ppm)
Hardhead	1,160	440	2.55	17.3	0.47
Carp	2,350	540	5.17	21.3	0.88
Sacramento Sucker	870	410	1.91	16.1	0.57
Sacramento Sucker	1,020	450	2.24	17.7	0.68
Sacramento Sucker	1,110	470	2.44	18.5	0.50
Sacramento Sucker	1,150	460	2.53	18.1	0.41
Sacramento Sucker	1,460	523	3.21	20.6	0.89
Smallmouth Bass	330	280	0.73	11.0	0.52
Largemouth Bass	390	315	0.86	12.4	0.64

Only the bass in the collection were upper level predators. However, the two individuals sampled in this collection were quite small and young. Comparably sized bass from other systems characteristically contain lower mercury accumulations than co-occurring larger adults (TSMP 1990, Slotton 1991, Slotton *et al.* 1996). The relatively elevated levels in the young smallmouth (0.52 ppm) and largemouth (0.64 ppm) bass taken in this collection are consistent with the other Englebright data in suggesting that there is a considerable amount of fish uptake of mercury in this system. However, a more comprehensive sampling should be undertaken before drawing any firm conclusion on this matter, particularly from a regulatory standpoint.

While similar fish could not be collected at both the reservoir and river sites upstream or downstream, the data indicate a significant general increase in mercury bioavailability to fish within the reservoir, even as compared to the most highly elevated upstream stretches of the Yuba River tributaries. What is most interesting is the consistently low levels of mercury accumulation, across a wide range of sizes and ages, in rainbow trout taken below Englebright Reservoir (Site 16).

DISCUSSION AND CONCLUSIONS

Biotic mercury presence and distribution in the Sierra gold region

A clear signature of anthropogenic mercury was present in the aquatic biota sampled throughout the historic Sierra Nevada gold region in this research. Concentrations ≥ 0.01 mg kg^{-1} (dry weight) were found in virtually all invertebrates sampled. On a wet weight basis, fish filet muscle mercury was ≥ 0.03 mg kg^{-1} at all sites (≥ 0.14 mg kg^{-1}, dry weight). Both invertebrates and fish demonstrated significantly higher mercury concentrations in regions that have sustained greatest intensities of gold mining pressure, both historically and at present.

Trout and invertebrate samples indicate relatively low current levels of mercury bioavailability in the majority of the Feather and American River watersheds. In contrast, significantly greater bioavailability was indicated by higher bioaccumulation of mercury in a number of areas. Notably higher mercury regions included the upper forks of the Yuba River, with the mid-reaches of the Middle and South Forks having the highest biotic mercury concentrations in that drainage. Other notably elevated mercury streams within the Sacramento river watershed included the mid-section of the Middle Fork of the Feather River, Deer Creek, particularly below Lake Wildwood, and tributaries throughout the gold mining region of the Bear River drainage. The North Fork of the Cosumnes River, in the San Joaquin watershed, demonstrated the highest concentrations of biotic mercury among all of the 57 study sites. Elevated to a lesser extent, but on a relative basis as compared to adjacent sites were the North Fork of the Middle Fork of the American River (49), and Spanish Creek (7, tributary to the North Fork Feather River). The above noted streams with elevated biotic mercury included the highest densities of active dredging operations, which also corresponded generally to the greatest historical mining intensities. At sites located upstream of heavily mined stretches, e.g. the Plumbago site (27) on the Middle Fork Yuba River and the headwaters collections on the Bear River (Site 44), significantly lower mercury concentrations were found throughout the food web, as compared to levels within and downstream of intensively mined reaches.

The relative biotic mercury concentrations found in this study can presumably be linked to relative concentrations of aqueous, bioavailable mercury moving down each of these streams. It is important to distinguish between *concentration* and *mass load*. Sites with the highest concentrations of mercury may not necessarily be the most important overall contributors of mercury to the downstream Delta/Bay system. However, with regard to potential mercury remediation projects in the Sacramento River watershed, it is precisely those regions identified as having the greatest mercury concentrations that offer the most realistic options for effective mitigation work.

One important conclusion of the survey work is that the elevated mercury regions did not demonstrate a point source signature. Where biotic accumulations of mercury were elevated, this elevation was generally distributed across many miles of stream or river. The elevated bioavailable mercury regions could thus be localized to specific tributaries or series of river miles, but not to highly localized "hot spot" point sources. This is consistent with the historic widespread use of mercury throughout the gold mining region and its subsequent redistribution downstream.

Fish mercury concentrations in relation to environmental and health concerns

While these data clearly indicate the differences in relative mercury bioavailability among the various streams of the region, the absolute concentrations in rainbow trout were all well below existing health criteria. Even at the highest mercury sites, the normalized 250 g rainbow trout, fresh weight, filet muscle mercury levels were less than 50% of the 0.5 ppm guidelines suggested by the California Department of Health Services and the Academy of Sciences, and $\leq 21\%$ of the existing U.S. FDA fish criterion of 1.0 ppm. The entire data set for 250 g normalized rainbow trout ranged between 0.03 and 0.21 mg kg^{-1} (ppm). Larger fish ranged higher but were still all within the 0.5 ppm guidelines. We conclude that there is relatively little direct health hazard associated with the consumption of rainbow trout from these Sierra Nevada streams and rivers. The notably elevated levels of mercury in edible muscle of fish from within Englebright Reservoir suggests that a problem may exist in some of the foothill reservoirs--one that may warrant additional study. The fact that this elevated mercury phenomenon was not additionally found downstream of the reservoir indicates that the foothill reservoir habitat may be trapping bioavailable mercury in addition to the bulk, inorganic mercury which deposits there with sediment.

Influence of reservoirs on downstream biotic mercury

It was expected that mercury bioavailability might be relatively low in the rivers and streams of this region, despite the presence of still considerable amounts of inorganic mercury from the gold mining era. This is because methyl mercury, the predominant form of mercury that enters and moves through the food web, requires a biological process, bacterial methylation, for the bulk of its production (Gilmour *et al.* 1992). The opportunity for bacterial mercury methylation or even the presence of significant bacterial populations is minimized in the fast moving, cold, clear water habitat typical of many of these Sierra Nevada foothill streams. However, once transported to calmer waters such as downstream reservoirs, turbid valley rivers, the Sacramento/San Joaquin Delta, and San Francisco Bay, the potential for bacterial methylation of mercury derived from the

Sierra gold mining region increases dramatically. The foothill reservoirs, in particular, are likely sites of enhanced mercury methylation. Limited prior analyses of fish from some of these reservoirs have indeed found markedly higher mercury concentrations than those found in this study of the upstream rivers (TSMP 1990, 1991, 1992). Our sampling in Englebright Reservoir also detected quite elevated levels of mercury in edible filet muscle from a variety of species.

We hypothesized that, as a result of enhanced mercury methylation within Sierra foothill reservoirs, there might be a detectable net export of bioavailable mercury from them to their downstream rivers. In contrast, the data collected in this study indicate the reverse. Not only do the reservoirs <u>not</u> appear to be net exporters of bioavailable mercury, but they seem to be acting as sinks for bioavailable as well as inorganic mercury. In most instances where we sampled upstream and downstream of Sierra foothill reservoirs, significantly *lower* mercury was found in the downstream biota, throughout the entire aquatic food web (e.g. upstream/downstream of Englebright, New Bullards Bar, and Camp Far West Reservoirs). We conclude that, despite the likely enhancement of mercury methylation within these reservoirs, the bioavailable mercury must be quickly taken up within the reservoir ecosystem itself, becoming largely unavailable for downstream transport. It was understood that these reservoirs must act as giant sinks for the inorganic mercury moving into them from upstream. The finding that they are also apparently not net exporters of bioavailable mercury is a particularly interesting and relevant result of this study. Production and consumption of methyl mercury in the reservoir water column appears to be in equilibrium.

In any case, collections of biotic indicator species from below the final dams and reservoirs of the main stems of the Feather, Yuba, Bear, and American Rivers demonstrated uniformly low levels of time-integrated mercury bioavailability as compared to the elevated mercury stretches identified in the gold mining region. The Cosumnes River in the San Joaquin watershed, which was extremely elevated in bioavailable mercury and is a rare un-dammed system, may represent a more direct source of bioavailable mercury to the Delta than any of the rivers in the Sierra Nevada portion of the Sacramento River watershed.

<u>Trophic feeding level relationship to mercury accumulation</u>

Within each site, mercury concentrations in biota generally corresponded to trophic feeding level, with higher trophic levels of invertebrates containing greater concentrations of mercury. Corresponding rainbow trout, which prey on all of these invertebrates to varying extents, had still higher mercury accumulations, while piscivorous fish such as native squawfish and the larger brown trout had the highest mercury concentrations of all. Trophic bioconcentration of mercury is thus indicated to be a dominant mode of mercury accumulation by biota in this region. For basic ecological research, an interesting aspect of this work is the finding that relative mercury concentrations in aquatic species may offer a useful tool for determining the relative, time-integrated trophic feeding habits of specific aquatic species.

Correlations between the mercury contents of biota of different trophic levels were similar, whether identical types of organism were used for the comparison or a variety of representatives of each trophic guild. This suggests that when identical invertebrate species are not available between sites, a variety of species within the same trophic feeding guild may be utilized as comparative general indicators of relative mercury bioavailability.

Inter-trophic mercury correlations between various groups of co-existing invertebrates were found to be uniformly stronger than mercury concentration correlations between invertebrates and corresponding trout. This is likely due to the relative site fidelity of stream invertebrates, as compared to trout, which can wander extensively throughout their lifetime accumulation of mercury.

Correlations between mercury in stream invertebrates and mercury in co-occurring trout were stronger with increasing invertebrate trophic level. Predatory invertebrate species such as Perlid stoneflies and Corydalid hellgrammites were found to be the best indicators of corresponding trout mercury levels. The excellent correspondence between larger, predaceous invertebrates and co-occurring trout may be a function of similar diet and, particularly in the case of the large hellgrammites, similar ages and thus similar periods of mercury integration. Mercury in smaller, younger organisms such as most mayflies, Hydropsychid caddis nymphs, and young predators may not correlate as well with trout mercury, but may instead be a better indicator of shorter term conditions of mercury bioavailability. Under potentially dramatic seasonally or annually changing conditions of mercury bioavailability, changes will be far less pronounced in older organisms as compared to more ephemeral species, for which the most recent time period represents a larger proportion of the entire lifetime accumulation (Slotton *et al.* 1995b). Thus, different organisms may be utilized for different types of information. Trout mercury is of direct interest for health reasons and provides a general indicator of regional, long-term mercury availability. Larger predaceous species may be utilized as surrogates for trout. The larger/older invertebrates of all types provide localized, long-term integration of relative mercury availability, when same types are compared. Finally, smaller/younger invertebrates can potentially be used as integrators of mercury conditions over shorter time scales. Ongoing research by our U.C. Davis Heavy Metals Limnology Group is investigating all of these areas.

Future Considerations

Stream invertebrates appear to be appropriate indicators for determining relative, time-integrated mercury bioavailability between sites throughout the Sierra Nevada gold region.

However, the nature of the trophic structure of the invertebrate community must be considered and potentially significant temporal changes should be taken into account. Invertebrates are more widely available than trout and, because they do not have the mobility of fish, their mercury accumulations can be linked with greater confidence to conditions directly at and upstream of a given locale. Certain invertebrate species can also function as surrogates for trout, with larger predatory types showing the strongest relationship. Other species may be useful in determining short-term mercury conditions. The great advantage of using native biota as indicators, as compared to standard water grab sampling protocol, is their natural and continuous integration of conditions over time and their accumulation of, by definition, the bioavailable fraction of mercury.

As this comprehensive survey indicates that the elevated mercury regions of the gold country watersheds are not of a point source nature, potential future mercury remediation efforts would probably be best directed toward regional approaches such as an improved mercury buy-back program through ongoing small-scale miners. Costly point-source engineering solutions are not supported by the data.

Future research projects include similar survey work in the Sierra Nevada gold region to the south, particularly the Cosumnes and Mokelumne Rivers, survey work throughout the California Coast Range mercury mining district and into the Delta, together with simultaneous investigation of the research questions highlighted above. Another major area of research will involve the study of how the various mercury loads to the Delta/Bay system behave once in that system, with a particular emphasis on the long-term potential bioavailability of different mercury compounds from a variety of sources.

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APPENDIX C

CONTROL STRATEGY EVALUATIONS

Mercury control strategy alternatives selected as potentially appropriate for the study area were evaluated using the following criteria. Criteria and subjective rankings are summarized in Table C-1. A summary of the results of control strategy evaluations is presented in Table C-2. Individual evaluations and discussion of the selected control strategies are presented following Table C-2.

Accessibility of Mercury: Where (and in what form and concentrations) is mercury accessible in the study area? Is mercury localized and concentrated or diffuse and widely distributed? For the purpose of source control evaluations, mercury present in the study area was partitioned into the following categories:

- Elemental mercury (i.e. quicksilver), present primarily among streambed sediments near or downstream from historical mining areas.
- Particulate (sediment-bound) inorganic mercury associated with riparian zone or instream sediments.
- Particulate and dissolved mercury in the water column.
- Mercury in biota.

Source Data Sufficiency: Are available data for mercury sources sufficient to implement the control strategy? Are additional data required?

Limitations of Controls: What are the primary factors limiting the effectiveness of the control strategy? How severely do these factors limit effectiveness?

Potential Benefits of Control Strategy: What are the expected benefits (both in the study area and in the Sacramento River downstream) of implementing the control strategy. Specifically:

- What is the estimated percentage of mercury loads removed (or controlled) by source control(s)?
- Would implementation of the controls result in significant increases in beneficial uses?

Potential Impacts of Source Controls: Are there potentially significant environmental or economic impacts associated with control strategy implementation? How severe are the expected impacts?

Costs: What is the expected relative cost of the mercury control strategy? Is the expected cost per kilogram of mercury controlled higher or lower than for other strategies?

Relevance Outside of the Study Area: Can implementation of the source control be considered a realistic pilot or demonstration project for other watersheds? More specifically:

- Can the control strategy be applied outside the study area?
- What specific factors or conditions are required (if any) for success of the control strategy?
- Will implementation of the strategy as a pilot or demonstration project provide new information useful for evaluating the application of the strategy elsewhere?

Table C-1. Summary of control strategy evaluation criteria.

	Control Strategies		
evaluation criterion	**1 (best)**	**2**	**3 (worst)**
% of in-place Hg sources removed or controlled	> 50%	25 - 50%	0%
Is Hg source data sufficient to implement strategy?	existing information is sufficient	some additional data are needed	extensive additional data needed
Limitations of strategy	minor	moderate	severe
impacts: environmental and economic impacts of implementation in study area	no significant impacts expected	potentially significant impacts expected	severe environmental or economic impacts expected
decrease in study area Hg loads and concentrations	significant decrease in Hg (> 25%)	moderate decrease in Hg (< 25%)	no long-term decrease in Hg expected
increase in study area beneficial uses	probable significant increase in uses supported	minor increase in uses supported possible	no net increase in uses supported expected
decrease in Sacramento River Hg loads	significant decrease in Hg (> 5%)	minor decrease in Hg (< 5%)	no long-term decrease in Hg expected
increase in Sacramento River beneficial uses	significant increase expected in uses supported	possible increase in uses supported	no increase expected
relative cost per unit of mercury controlled	low cost per kg of mercury controlled	moderate cost per kg of mercury controlled	high cost per kg of mercury controlled
value as pilot or demonstration project	(a) implementation would provide new information valuable in evaluating controls for other regions AND (b) control strategy widely applicable elsewhere	(a) implementation would provide new information valuable in evaluating controls for other regions AND (b) limited applicability of control strategy elsewhere	(a) implementation would NOT provide new information valuable in evaluating controls OR (b) control strategy NOT applicable elsewhere

Table C-2. Summary of control strategy evaluations.

evaluation criteria	Control Strategies: Hg recycl ing	tailings reclama- tion	tailings removal	stream channel dredging	reservoir dredging	reservoir operation changes	H_2O treatment facilities	mining regula- tion
% of in-place Hg sources removed or controlled	2	3	2	3	3	3	3	3
Is Hg source data sufficient to implement strategy?	1	2	2	3	2	1	1	1
impacts of implementation in study area	1	1	3	3	3	3	2	3
decrease in study area Hg loads and concentrations	2	2	2	3	3	3	3	3
increase in study area beneficial uses	3	2	3	3	3	3	3	3
decrease in Sacramento River Hg loads	2	2	2	3	3	2	2	3
increase in Sacramento River beneficial uses	3	3	3	3	3	3	3	3
relative cost per unit of mercury controlled	1	2	3	3	3	3	3	3
value as pilot or demonstration project	2	2	3	3	3	3	3	3
unweighted average:	**1.9**	**2.1**	**2.6**	**3**	**2.9**	**2.7**	**2.6**	**2.8**

Stabilization and Reclamation of Hydraulic Mining Tailings

Summary: This alternative consists of the reclamation and stabilization of localized deposits of sediments from historical hydraulic mining activity to prevent erosion of the tailings and associated mercury into study area streams.

Access to Mercury • percent of study area Hg loads and stores accessed *Rank: 3*	This alternative targets localized deposits of hydraulic mining tailings in the study area. The proportion of mercury associated with mining tailings is not known, and the volume of tailings stored in the study area is thought to be less extensive than in watersheds with more shallow gradients (e.g. Bear River). Although the majority of tailings from hydraulic mining in the Yuba River basin have already been transported to the Sacramento River and downstream, substantial deposits are thought to remain in some tributary basins (James 1993).
Mercury Source Data • Is mercury source data sufficient to implement control strategy? *Rank: 2*	This alternative would require additional information to locate accessible significant tailings deposits in the watershed.
Control Strategy Limitations *Rank: 2*	Effectiveness in reducing annual Sacramento River mercury loads is dependent on (1) the percentage of mercury loads associated with localized mine tailing sediments in the study area, and (2) the frequency and magnitude of remobilization of those sediment stores. This option leaves existing mercury stores in place while reducing the rate of mercury loading from the study area.
Potential Impacts • environmental • economic *Rank: 1*	The alternative would require the stabilization and reclamation of localized concentrations of hydraulic mining tailings, located primarily in the riparian zone of study area tributaries. May require protection of tailings from erosion by high stream flows and import of soils adequate to support vegetation. Potential impacts may be limited to temporary disturbance of riparian zone habitat. No significant economic impacts (exclusive of the cost of implementation) are expected if this alternative is implemented.
Study Area Benefits • loading and instream concentrations • beneficial uses *Rank (loading): 2* *Rank (uses): 3*	Long term control of mining tailings and associated mercury from study area stream basins, resulting in reduced sediment and total mercury loads during high flow events sufficient to remobilize stored sediment. There would probably be little or no effect on loads or concentrations under less extreme flow conditions. Decreased sediment loads may extend maintenance periods for study area reservoirs. There may also be a minor increase in stable riparian habitat as a result of tailings stabilization and reclamation. Based on mercury concentrations in water and biota, streams in the study area drainages are not adversely impacted by current mercury concentrations, so there would be no appreciable increase in the ability to support beneficial uses in the study area.
Downstream Benefits • loading and instream concentrations • beneficial uses *Rank (loading): 2* *Rank (uses): 3*	Potential decrease of less than 4% of total mercury concentrations and average annual loads in the Sacramento River. May also reduce sedimentation of stream channels and reservoirs. Would not result in a significant increase in the ability to support beneficial uses.

Costs • $/kg compared to other controls *Rank: 2*	Primary expected costs of this alternative include: • locating and prioritizing hydraulic mining tailings suitable for reclamation • stabilization of tailings in lower riparian zone • vegetative reclamation of tailings Summary: It is expected that this option would result in a moderate cost per kg of mercury controlled.
Relevance • pilot project value outside of study area *Rank: 2*	If successful, this alternative could also be implemented effectively in other regions with substantial mercury-enriched mining tailings subject to erosion, particularly in regions with inactive historic mercury mines. However, while implementation would provide data specific to the effectiveness of mercury control, information is already available on controlling metal pollution from mine tailings drainage by similar methods. Summary: Moderate pilot project value outside of study area

Removal of Hydraulic Mining Tailings

Summary: This strategy consists of the removal and disposal or storage of localized riparian zone deposits of tailings from historic hydraulic and instream mining operations.

Access to Mercury • percent of study area Hg loads and stores accessed *Rank: 2*	This alternative targets localized deposits of hydraulic mining tailings in the study area. The proportion of mercury associated with mining tailings is not known, and the volume of tailings stored in the study area is thought to be less extensive than in watersheds with more shallow gradients (e.g. Bear River). Although the majority of tailings from hydraulic mining in the Yuba River basin have already been transported to the Sacramento River and downstream, substantial deposits are thought to remain in some tributary basins (James 1993).
Mercury Source Data • Is mercury source data sufficient to implement control strategy? *Rank: 2*	Additional information would be required to implement effectively: e.g. to locate large accessible deposits of tailings and to estimate concentrations and masses.
Control Strategy Limitations *Rank: 2*	Effectiveness in reducing annual Sacramento River mercury loads is dependent on (1) the percentage of mercury loads associated with localized mine tailing sediments in the study area, and (2) the frequency and magnitude of remobilization of those sediment stores. This alternative may require long-term storage/disposal of mining tailings.
Potential Impacts • environmental • economic *Rank: 3*	The alternative would require the removal and disposal of huge volumes of tailings, located primarily in the riparian zone of study area tributaries. Potential impacts include temporary loss of riparian zone habitat, and short-term increases in sedimentation of study area streams and reservoirs. Local impacts may exceed the benefits of expected improvements in local water quality. This alternative would likely require a CEQA Environmental Impact Assessment. No significant local economic impacts (exclusive of the cost of implementation) are expected if this alternative is implemented.
Study Area Benefits • loading and instream concentrations • beneficial uses *Rank (loading): 2* *Rank (uses): 3*	Permanently removes mining tailings and associated mercury from study area stream basins, resulting in reduced sediment and total mercury loads during high flow events sufficient to remobilize stored sediment. There would probably be little or no effect on loads or concentrations under less extreme flow conditions. Based on mercury concentrations in water and biota, streams in the study area drainages are not adversely impacted by current mercury concentrations, so there would be no appreciable increase in the ability to support beneficial uses in the study area.
Downstream Benefits • loading and instream concentrations • beneficial uses *Rank (loading): 2* *Rank (uses): 3*	Potential decrease of less than 4% of total mercury concentrations and average annual loads in the Sacramento River. However, in the short term, permanent removal of *potential* mercury loads from the study area may exceed the average annual mercury load in the Sacramento River. May also reduce sedimentation of stream channels and reservoirs in the long term. Would not result in a significant increase in the ability to support beneficial uses.

Costs • $/kg compared to other controls *Rank: 3*	Primary expected costs of this alternative include: • locating hydraulic mining tailings suitable for recovery • recovery and transport of tailings • storage/disposal of recovered tailings • mitigation of local environmental impacts Summary: It is expected that this option would result in the relatively high cost per kg of mercury removal.
Relevance • pilot project value outside of study area *Rank: 3*	If successful, this alternative could also be implemented effectively in other regions with substantial mercury-enriched mining tailings subject to erosion, particularly in regions with inactive historic mercury mines. Summary: Low pilot project value outside of study area

Stream Channel Dredging

Summary: This alternative consists of the removal and disposal of instream sediments and associated mercury from historical hydraulic mining activity.

Access to Mercury • percent of study area Hg loads and stores accessed *Rank: 3*	This alternative would target instream deposits of hydraulic mining tailings in the study area. The proportion of mercury associated with instream sediments is not known, but probably represents only a small portion of the mercury stores in the study area, based on current loading rates and historical source information. Although the majority of tailings from hydraulic mining in the Yuba River basin have already been transported to the Sacramento River and downstream, substantial deposits are thought to remain in some tributary basins (James 1993).
Mercury Source Data • Is mercury source data sufficient to implement control strategy? *Rank: 3*	Extensive additional data would be needed to locate and estimate mass of mercury in streambeds.
Control Strategy Limitations *Rank: 3*	Effectiveness in reducing annual Sacramento River mercury loads is dependent on (1) the percentage of mercury loads associated with instream deposits of hydraulic mining tailings in the study area, and (2) the frequency and magnitude of remobilization of instream sediment stores. This option only addresses instream mercury stores, and leaves other sources intact. Reductions in mercury loading would probably be temporary.
Potential Impacts • environmental • economic *Rank: 3*	The alternative would require the dredging and disposal of instream sediments. Impacts to study area ecosystem (destruction of instream and riparian habitat and biota) would be significant and extensive. Significant economic impacts (exclusive of the cost of implementation) are also expected due to extensive resource destruction. Would result in severe reduction in beneficial uses supported in study area.
Study Area Benefits • loading and instream concentrations • beneficial uses *Rank (loading): 3* *Rank (uses): 3*	Long term control of mining tailings and associated mercury from study area stream basins, resulting in reduced sediment and total mercury loads during high flow events sufficient to remobilize stored sediment. There would probably be little or no effect on loads or concentrations under less extreme flow conditions. Decreased sediment loads may extend maintenance periods for study area reservoirs. There may also be a minor increase in stable riparian habitat as a result of tailings stabilization and reclamation. Based on mercury concentrations in water and biota, streams in the study area drainages are not adversely impacted by current mercury concentrations, so there would be no appreciable increase in the ability to support beneficial uses in the study area.
Downstream Benefits • loading and instream concentrations • beneficial uses *Rank (loading): 3* *Rank (uses): 3*	Potential short-term decrease of less than 4% of total mercury concentrations and average annual loads in the Sacramento River. May also reduce sedimentation of stream channels and reservoirs. Would not result in a significant increase in the ability to support beneficial uses.

Costs • \$/kg compared to other controls *Rank: 3*	Primary expected costs of this alternative include: • developing access to hundreds of miles of stream bed • dredging of up to hundreds of miles of streams • disposal of dredgings (as hazardous waste?) • Environmental Impact Assessment Summary: It is expected that this option would result in very high cost per kg of mercury removed from the study area.
Relevance • pilot project value outside of study area *Rank: 3*	Although this control strategy could be implemented in other regions with substantial mercury-enriched instream sediments, there is already adequate information available to evaluate this alternative. Benefits, impacts and costs would probably be similar in other regions. Implementation in the study area would not develop any additional information useful in evaluating this alternative. Summary: Low pilot project value outside of study area.

Reservoir Dredging

Summary: This alternative consists of the removal and disposal of sediments and associated mercury deposited in study area reservoirs.

Access to Mercury • percent of study area Hg loads and stores accessed *Rank: 3*	This alternative would target only mercury associated with in-place reservoir sediments. Although the proportion of mercury associated specifically with reservoir sediments is not known, the proportion of total mercury loads associated with suspended sediments in the lower Yuba River is 50-60% on average. Although the majority of mercury from hydraulic gold mining in the Yuba River basin have already been transported to the Sacramento River and downstream (James 1993), reservoir sediments may contain substantial mercury stores.
Mercury Source Data • Is mercury source data sufficient to implement control strategy? *Rank: 2*	Some additional data would be required to implement this strategy: e.g. mercury mass in sediments; frequency of resuspension; rate of deposition; percent of mercury loads that may bypass during high flows.
Control Strategy Limitations *Rank: 3*	Effectiveness in reducing annual Sacramento River mercury loads is dependent on (1) the percentage of mercury loads associated with in-place reservoir sediments in the study area, and (2) the frequency and magnitude of remobilization of in-place reservoir sediments. • Little or no reduction in dissolved mercury or mercury associated with suspended sediments. • Would require repeated dredging to be effective over the long term. • Leaves upstream mercury stores intact.
Potential Impacts • environmental • economic *Rank: 3*	The alternative would require dredging and disposal of reservoir sediments on a regular (probably annual) basis. Impacts to reservoir ecosystems (lentic habitat and biota) from annual disturbance would probably be substantial. Would probably result in reduction in beneficial uses supported in study area reservoirs. Would probably require alteration of reservoir operations. Significant economic impacts (exclusive of the cost of implementation) can be expected if resuspension of sediments near reservoir outlets reduces ability to provide water of adequate quality for drinking water supply, downstream aquatic biota, irrigation deliveries, etc.
Study Area Benefits • loading and instream concentrations • beneficial uses *Rank (loading): 3* *Rank (uses): 3*	Reduction in instream suspended sediments and associated mercury and other pollutants downstream from major reservoirs. No significant reductions in instream mercury concentrations and loads upstream from major reservoirs. Based on mercury concentrations in water and biota, streams in the study area drainages are not adversely impacted by current mercury concentrations, so there would be no appreciable increase in the ability to support beneficial uses in the study area.
Downstream Benefits • loading and instream concentrations • beneficial uses *Rank (loading): 3* *Rank (uses): 3*	Potential decrease of less than 2% of total mercury concentrations and average annual loads in the Sacramento River. May reduce sedimentation of downstream channels and streambeds. Permanent removal of sediment-associated mercury from study area. Would not result in a significant increase in the ability to support beneficial uses.

Costs • $/kg compared to other controls *Rank: 3*	Primary expected costs of this alternative include: • regular/annual dredging operations • disposal of dredged materials Summary: It is expected that this option would result in a relatively high cost per kg of mercury removed from the study area.
Relevance • pilot project value outside of study area *Rank: 3*	Although this alternative could be implemented effectively in other regions with substantial mercury-enriched reservoir sediments, there is already adequate information available to evaluate this alternative. Benefits, impacts, and costs would be similar in other regions. Implementation in the study area would probably not develop any additional information useful in evaluating this alternative. Summary: low pilot project value

Reservoir Operational Changes

Summary: This alternative consists of changing the operation of major reservoirs to maximize deposition of sediment and associated mercury from the water column. This strategy could be combined with reservoir dredging (see above) for sediment removal.

Access to Mercury • percent of study area Hg loads and stores accessed *Rank: 3*	This alternative would target mercury associated with suspended sediments in study area surface waters. The proportion of total mercury loads associated with suspended sediments in lower Yuba River is 50-60% on average.
Mercury Source Data • Is mercury source data sufficient to implement control strategy? *Rank: 1*	Source data is sufficient; no additional data needed to evaluate this strategy.
Control Strategy Limitations *Rank: 3*	Effectiveness in reducing annual Sacramento River mercury loads is dependent on the ability of altered reservoir operations to remove suspended sediments. • Would probably require regular dredging to be effective for the long term. • May conflict with or compromise primary objectives of reservoir operations (e.g. for water supply, power supply, and flood control). • Leaves upstream mercury sources intact.
Potential Impacts • environmental • economic *Rank: 3*	The primary impact of this alternative would be to decrease the useful life of reservoirs by increased sedimentation, or increase the frequency of maintenance. Other potentially significant impacts include decreased water storage and flood control capacity, and decreased water and power supply. Significant economic impacts (exclusive of the cost of implementation) would be associated with the any decrease in the ability of study area reservoirs to support these uses. Altered flow regimes could also result in significant impacts to downstream aquatic biota and habitat.
Study Area Benefits • loading and instream concentrations • beneficial uses *Rank (loading): 2* *Rank (uses): 3*	Reduction of sediments and associated mercury (and other pollutants) downstream from reservoirs. No significant reduction in dissolved mercury concentrations. No reductions of mercury concentrations upstream from study area reservoirs. Based on mercury concentrations in water and biota, streams in the study area drainages are not adversely impacted by current mercury concentrations, so there would be no appreciable increase in the ability to support beneficial uses in the study area.
Downstream Benefits • loading and instream concentrations • beneficial uses *Rank (loading): 2* *Rank (uses): 3*	Potential decrease of less than 2% of total mercury concentrations and average annual loads in the Sacramento River. May also reduce concentrations and loads of other sediment associated pollutants. No significant reduction in dissolved mercury concentrations. Would not result in a significant increase in the ability to support beneficial uses.

Costs • $/kg compared to other controls *Rank: 3*	Primary expected costs of this alternative include: • developing new reservoir operational models • increased frequency of reservoir maintenance • loss of revenues from water and power supply operations Summary: It is expected that this option would result in a high cost per kg of mercury controlled or removed from the study area.
Relevance • pilot project value outside of study area *Rank: 3*	This alternative could be implemented effectively in other regions with substantial mercury-enriched suspended sediments in surface waters upstream from major reservoirs. However, there is probably already adequate information available to evaluate this alternative for other regions. Benefits, impacts, and costs would likely be similar in other regions. Implementation in the study area would not develop additional information useful in evaluating this alternative. Summary: low pilot project value outside of study area

Water Treatment for Mercury Removal

Summary: This alternative consists of treatment of study area surface waters to remove mercury. This alternative is essentially equivalent to "end-of-pipe" treatment.

Access to Mercury • percent of study area Hg loads and stores accessed *Rank: 3*	This alternative targets total mercury loads carried by study area streams. Percent of loads accessed is directly proportional to percent of flows treated.
Mercury Source Data • Is mercury source data sufficient to implement control strategy? *Rank: 1*	Source data is sufficient; no additional data needed to evaluate this strategy.
Control Strategy Limitations *Rank: 2*	Effectiveness in reducing annual Sacramento River mercury loads would be dependent on treatment efficiency. Current treatment technologies are capable of removing more than 90% of mercury concentrations typically observed in municipal wastewater, but are less efficient at the relatively low concentrations observed in study area streams. • This option addresses instream mercury, but leaves sources intact. • Would require treatment plant(s) with design capacity of approximately 20,000 MGD (or more) to treat peak flows.
Potential Impacts • environmental • economic *Rank: 2*	The alternative would require building very large (or very many) water treatment facilities. Aside from the potentially substantial impacts from construction and access development, impacts to study area ecosystem (instream and riparian habitat and biota) would probably not be significant. Significant economic impacts (exclusive of the cost of implementation) are not expected. Would probably not result in a reduction in beneficial uses supported in study area.
Study Area Benefits • loading and instream concentrations • beneficial uses *Rank (loading): 3* *Rank (uses): 3*	Decreased concentrations and loads of mercury and other pollutants downstream from treatment facilities only. Based on mercury concentrations in water and biota, streams in the study area drainages are not adversely impacted by current mercury concentrations, so there would be no appreciable increase in the ability to support beneficial uses in the study area.
Downstream Benefits • loading and instream concentrations • beneficial uses *Rank (loading): 2* *Rank (uses): 3*	Potential decrease of less than 4% of total mercury concentrations and average annual loads in the Sacramento River (decrease would be proportional to percent of total flows treated). Would also reduce concentrations and loads of other pollutants and sediments. Would not result in a significant increase in the ability to support beneficial uses.
Costs • $/kg compared to other controls *Rank: 3*	Primary expected costs of this alternative include: • capital expenses for construction of water treatment facilities • annual operational expenses for treatment facilities • disposal/reuse of biosolids, etc. Summary: It is expected that this option would result in the highest possible cost per kg of mercury removed from the study area.

Relevance • pilot project value outside of study area *Rank: 3*	Although this alternative could be implemented in other regions with substantial mercury-enriched surface water, there is already adequate information available to evaluate this alternative. Benefits, impacts, and costs would likely be similar in other regions. Implementation in the study area would not develop any additional information useful in evaluating this alternative. Summary: low pilot project value

Additional Regulation of Gold Mining Activity

Summary: This option consists of limitation or prohibition of instream gold mining activity, or additional regulation of gold mining methods, for the purpose of limiting introduction or resuspension of sediment-associated and elemental mercury in study area streams.

Access to Mercury • percent of study area Hg loads and stores accessed *Rank: 3*	This alternative would target mercury loads associated with resuspension or introduction of sediments and associated mercury due to small-scale gold mining activities (primarily suction dredge operations). Although the proportion of mercury loading associated with contemporary gold mining has not been investigated, it probably represents a negligible fraction of the total loading to the Sacramento River system (mercury is no longer widely used to process gold in the field). In comparison to mobilization and transport of sediment-associated and elemental mercury by natural processes (e.g. erosion of riparian zone soils and historical hydraulic mining tailings, and scouring of stream beds during high flows), the effects of modern gold mining practices are expected to be insignificant.
Mercury Source Data • Is mercury source data sufficient to implement control strategy? *Rank: 1*	Source data is sufficient; no additional data needed to evaluate this strategy.
Control Strategy Limitations *Rank: 3*	This strategy addresses an extremely limited percentage of study area mercury loads. In addition: • Existing mercury sources are left intact. • Mining activity (methods and schedules) in the study area is already significantly restricted. • May actually increase mercury loads (see Potential Impacts)
Potential Impacts • environmental • economic *Rank: 3*	The alternative would require additional restrictions on study area gold mining activities. Depending on the extent of these restrictions, significant to severe local economic impacts (exclusive of the cost of implementation) can be expected for gold miners and businesses supported by the gold mining community. Impacts to the study area ecosystem (instream and riparian habitat and biota) would not be significant. This alternative would probably not result in reduction of other beneficial uses (excluding mining) supported the study area. Note: elemental mercury is often collected in and near study area streams by gold panners and dredge operators (primarily to extract any associated gold). To the degree that restriction or prohibition of mining activities would tend to reduce the ongoing collection and removal of elemental mercury from the study area, it may result in a net decrease in mercury removed and consequently an increase in mercury loading and instream concentrations in the study area and downstream.
Study Area Benefits • loading and instream concentrations • beneficial uses *Rank (loading): 3* *Rank (uses): 3*	No decrease in average annual loads in the study area streams is expected. May seasonally reduce sediment and mercury concentrations due to mining activity during lower flows. Based on mercury concentrations in water and biota, streams in the study area drainages are not adversely impacted by current mercury concentrations, so there would be no appreciable increase in the ability to support beneficial uses in the study area.

Downstream Benefits • loading and instream concentrations • beneficial uses *Rank (loading): 3* *Rank (uses): 3*	No decrease in average annual loads or mercury concentrations in the Sacramento River. Would not result in a significant increase in the ability to support beneficial uses.
Costs • $/kg compared to other controls *Rank: 3*	Primary expected costs of this alternative include: • development of new regulations • implementation and enforcement • mitigation of economic impacts (?) Summary: Because of the negligible reduction in mercury loads, it is expected that this option would result in a relatively high cost per kg of mercury controlled.
Relevance • pilot project value outside of study area *Rank: 3*	Few (if any) other mercury-rich regions support small-scale mining activity at the levels occurring in the study area. For this reason, the relevance of this alternative to other regions is extremely limited. Economic impacts would probably be lower in other regions, while the relative costs of mercury control would likely be higher. Summary: low pilot project value outside of study area

Mercury Recovery and Recycling

Summary: This alternative consists of implementing a "buy-back" or recycling program for mercury recovered from study area streams. The primary participants in the program are expected to be the recreational and commercial gold dredgers. Mercury recovered by participants in the field would be collected in central locations to be sold to commercial recycling operations at market value.

Access to Mercury • percent of study area Hg loads and stores accessed *Rank: 2*	This alternative targets the most accessible and concentrated form of mercury stores in the study area. The percentage of total mercury present in easily accessible elemental form is not known, however. This method would not specifically target mercury in more diffuse forms such as historical hydraulic mining tailings, but may serve to recover elemental mercury downstream from these areas.
Mercury Source Data • Is mercury source data sufficient to implement control strategy? *Rank: 1*	No additional mercury source data are necessary to implement this alternative. Moreover, implementation would provide additional data regarding the distribution of mercury throughout the study area.
Control Strategy Limitations *Rank: 2*	Effectiveness is dependent on voluntary participation in program. Accesses only the most easily collected mercury in the watershed.
Potential Impacts • environmental • economic *Rank: 1*	The expected participants in the recovery program are already working in the study area and this option is not expected to result in increased (or decreased) use or disturbance of the study area. Compensation would be set at a level insufficient to encourage mining specifically for the purpose of mercury recovery. No significant environmental or economic impacts are expected if this alternative is implemented.
Study Area Benefits • loading and instream concentrations • beneficial uses *Rank (loading): 2* *Rank (uses): 3*	Permanently remove elemental mercury directly from study area streams, resulting in decreased instream mercury concentrations and reduced total mercury loads. Insufficient information to estimate magnitude of decrease, but the elemental form of mercury is relatively mobile and most of the mercury recovered is expected to come from instream sediments and cobble, and the immediate riparian zone. Based on mercury concentrations in water and biota, Yuba River drainage streams are not adversely impacted by current mercury concentrations, so there would be no appreciable increase in the ability to support beneficial uses in the study area.
Downstream Benefits • loading and instream concentrations • beneficial uses *Rank (loading): 2* *Rank (uses): 3*	Potential decrease of less than 4% of total mercury concentrations and annual loads in the Sacramento River. However, in the short term, permanent removal of *potential* mercury loads from the study area may exceed the average annual mercury load in the Sacramento River. Would not result in a significant increase in the ability to support beneficial uses.

Costs • $/kg compared to other controls *Rank: 1*	Primary expected costs of this program include: • development of public education and promotional materials for program • cost of equipment for storage and transport of recovered mercury Summary: It is expected that this option would result in a relatively low cost per kg of mercury removed from the study area.
Relevance • pilot project value outside of study area *Rank: 2*	This alternative could be implemented successfully in other regions where elemental mercury was used in historical gold mining activity (although there are few other historical gold or mercury mining regions that currently support small-scale mining activity at the levels occurring in the study area.) However, this strategy could serve as a model for agency and special interest group cooperation for resolving other watershed related issues. Although the control strategy described is specific to mercury, he program could probably not be successfully transferred outside of the study area, due primarily to the lack of high concentrations of easily accessible elemental mercury outside of the historical gold mining region. Summary: Moderate pilot project value outside of study area

APPENDIX D:
PROJECT QAPPs

Quality Assurance Project Plan for the Water Quality Sampling portion of the Sacramento River Mercury Control Planning Project

November, 1995

Prepared by
Larry Walker Associates
for the
Sacramento Regional County Sanitation District

PROJECT MANAGEMENT

Title and Approval Sheet

QUALITY ASSURANCE PROJECT PLAN FOR THE WATER QUALITY SAMPLING PORTION OF THE SACRAMENTO RIVER MERCURY CONTROL PLANNING PROJECT

Implemented by the Sacramento Regional County Sanitation District

Approvals:

	Cheryl Creson	8/22/95
Project Manager	Cheryl Creson, Water ~~Quality~~ Division Chief, SRCSD	Date
	Armand Ruby	8/3/95
QA Manager	Armand Ruby, Senior Environmental Scientist, Larry Walker Assoc.	Date
	E. Tsalkitzis	8/8/95
QA Officer	~~Nicolas Bloom,~~ Frontier Geosciences EFROSINI TSALKITZIS	Date
	Michael T. Lehtola	8/14/95
QA Officer	~~Wennilyn Fua~~, Anlab MICHAEL T. LEHTOLA	Date
~~EPA Project Manager~~		Date
	N/A GAF	
~~EPA QA Manager~~		Date
	Greg Frantz	11/6/95
State Board Contract Manager	Greg Frantz, California State Water Resources Control Board	Date

CONTENTS

FIGURES

TABLES

APPENDICES

Distribution List

Cheryl Creson, SRCSD

Greg Frantz, SWRCB

Bill Croyle, CVRWQCB

Technical Advisory Committee:

Dick Zembec, US Forest Service (USFS)
Jerry Miller, Desert Research Institute
Rick Humphreys, State Water Resources Control Board
Ron Churchill, Division of Mines and Geology
Sean Hogan, USEPA - Region 9
Chris Stathos, Mother Lode Skin Diving Shops
Peter Richerson , UC Davis
Dave Sbaffi, Cal Sierra Development Company
Michael Pickering, Brush Creek Mining and Development Co.
Steve Swarzbach, U.S. Fish and Wildlife Service
David Crane, California Dept. of Fish and Game
Don Porcella, Electric Power Research Institute
Joseph Domagalski, USGS

Project Organization and Responsibility

This project will be managed by the Sacramento Regional County Sanitation District (SRCSD). The project manager from the SRCSD is Ms. Cheryl Creson. She is currently Chief of Sacramento County's Water Quality Division.

The project quality assurance manager will be Armand Ruby, Senior Environmental Scientist with Larry Walker Associates.

Sample collection and other data acquisition work will be conducted by the Engineering Consultant, Larry Walker Associates (LWA), an engineering firm located in Davis, California.

Analysis of water samples for mercury concentrations will be carried out by Frontier Geosciences, an analytical laboratory located in Seattle, Washington.

Analysis of water samples for suspended solids concentrations will be carried out by Anlab, an analytical laboratory located in Sacramento, California.

Flow measurements will be provided by the Yuba County Water Agency, the U.S. Geological Survey, the California Department of Water resources, and other water agencies responsible for recording stream flow data in the study area.

The principal data user and decision-maker for this project will be the Central Valley Regional Water Quality Control Board (CVRWQCB). This state agency will be responsible for incorporating mass load estimates and proposed control measures into its Mass Emissions Strategy for heavy metals in the Sacramento River watershed.

A technical advisory committee (TAC), consisting of staff from the SRCSD, the State Water Resources Control Board (SWRCB), the Central Valley Regional Water Quality Control Board, the U.S. Forest Service, the U.S. Fish and Wildlife Service, the Desert Research Institute, the California Division of Mines and Geology, the California Department of Fish and Game, the University of California at Davis, U.S. EPA Region IX, U. S. Geological Survey, and commercial and recreational mining interests will serve as technical reviewers for the project. The TAC has reviewed this QAPP and will be responsible for the review of the site selection report and the final project report.

The organizational structure is shown in Figure 1.

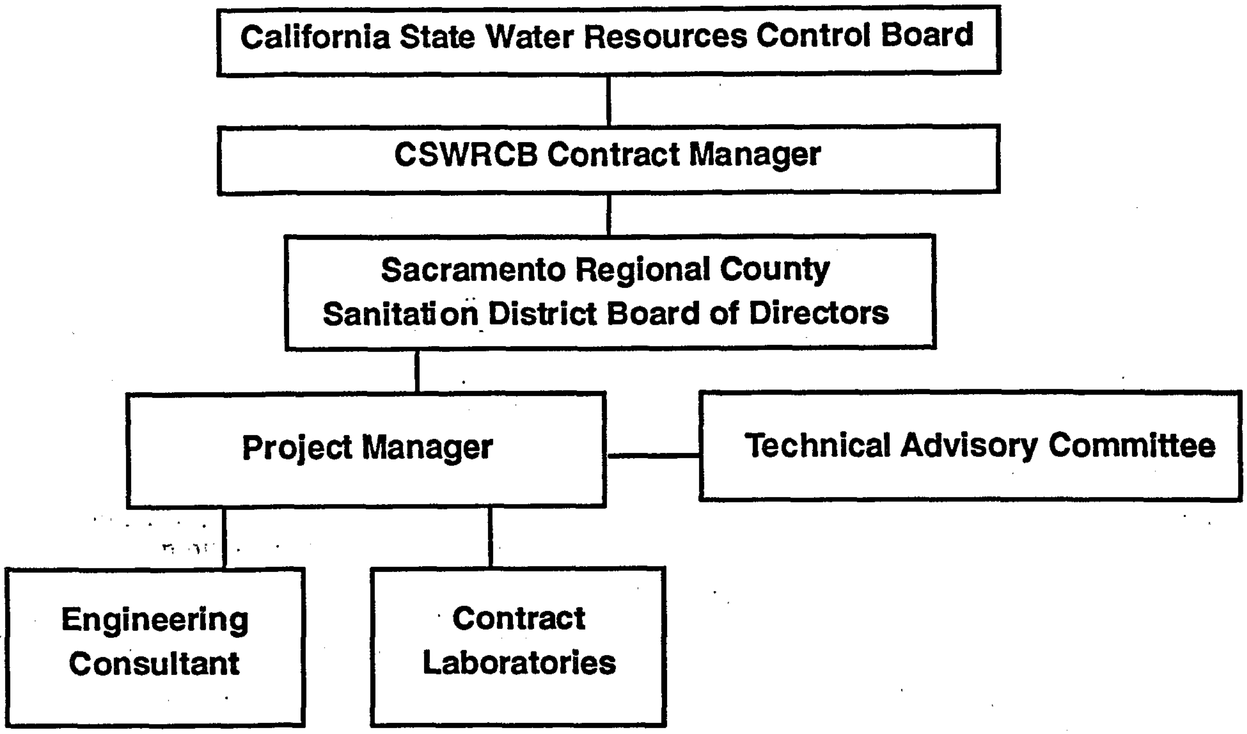


Figure 1 Management Structure
Sacramento River Mercury Control Planning Project

Problem Definition

Mercury in the Sacramento River Watershed

The CVRWQCB has determined that mercury causes an impairment of the aquatic habitat beneficial use in the Sacramento River between the Colusa Basin Drain and the Sacramento-San Joaquin Delta (SWRCB 1992a). The Department of Health Services has issued a consumer advisory limiting human intake of fish in the Sacramento-San Joaquin Delta (*ibid*).

Gold mining areas in the Feather River, Yuba River, and Bear River watersheds have been shown to be significant sources of mercury (CVRWQCB, 1987). However, point and nonpoint sources within these watersheds have not been identified or quantified in sufficient detail to facilitate the formulation of a strategy for controlling mercury emissions. For example, while mine tailings are known sources of mercury, the relative contribution to total loads in the Sacramento River from this source is not known (Montoya, et al., 1988) and has not been estimated using results of water column monitoring.

In 1986, the CVRWQCB conducted a survey of mercury contamination of sediment and fish throughout the Sacramento River watershed. Mercury was detected in elevated levels in sediment in the Yuba and Bear Rivers, Cache Creek, Putah Creek, and Stony Creek (CVRWQCB, 1987). Mercury levels in fish captured in water bodies in certain tributaries of the Sacramento River exceeded the National Academy of Sciences guideline to protect aquatic resources and their predators (0.50 ppm). These mercury bioaccumulation problems were observed in portions of the coast range where mercury is naturally occurring, in the Sierra Nevada Range where mercury was used (and is still used) to process gold, and in the Delta.

Regulation of Non-point Sources

Section 303(d) of the 1987 Clean Water Act (CWA) requires states to identify Water Quality Limited Segments (WQLS) where standards are not attainable after implementation of technology-based requirements (Best Available Technology/Best Control Technology). The Sacramento River from Shasta Dam to the Delta has been identified as a WQLS in the California Water Quality Assessment (SWRCB 1992a). This segment of the Sacramento River has also been given the highest ranking in terms of both resource value and degree of impairment by the State Board's Clean Water Strategy (SWRCB 1991).

Section 319(b) of the CWA requires that states implement nonpoint source (NPS) management programs and that these management programs involve public and private agencies and organizations which have expertise in control of nonpoint sources of pollution. Additionally, states are directed to develop NPS management plans on a watershed-by-watershed basis. Section 319(c) states that management plans also should be developed in cooperation with entities which are actively planning for the implementation of nonpoint source pollution controls.

Existing Management Plan: the TMDL Process

The CVRWQCB has begun a Total Maximum Daily Load (TMDL) process for heavy metal loadings (including mercury) from point and nonpoint sources in the Sacramento River watershed. This TMDL process includes the development of a mass emission strategy, identification of nonpoint sources, implementation of abatement and management programs, ambient monitoring, and monitoring of POTW and stormwater discharges.

Activities currently underway include development of a mass emission strategy by the CVRWQCB; implementation of mine drainage abatement projects by the CVRWQCB, the U.S. EPA, the U.S. Forest Service, and mine owners; as well as development of a stormwater management program and monitoring of POTW and stormwater discharges by the City and County of Sacramento (SWRCB 1992c). The monitoring data used in the TMDL process come from special studies, self-monitoring programs imposed on dischargers, and ongoing monitoring programs operated by the CVRWQCB, the Department of Water Resources, the United States Geological Survey, and other local, state, and federal agencies.

Need for Additional Information

One of the limiting factors of many previous (and continuing) mercury studies has been that mercury levels in surface waters are usually below the analytical detection limits employed. Because of this, much of the information available regarding mercury concentrations in surface waters is of little use in identifying and characterizing sources.

To address the problem of high detection limits, and to further refine knowledge regarding upstream sources, the CVRWQCB initiated a two-year, watershed-wide mercury survey in 1992. This reconnaissance-level survey used methods capable of detecting mercury in water at concentrations in the 0.01 to 0.25 ng/L (parts per trillion) range (SWRCB, 1992b). Samples were drawn twice each year. Six sites located on the Sacramento River were sampled during both years. Twelve sites in northern Sacramento Valley reservoirs were sampled during the first year, and eleven sites in southern Sacramento Valley reservoirs were sampled during the second year. The results of this survey have provided important information regarding mercury sources on a region-wide basis. However, because the number of potential sources is much larger than the number of monitoring sites, further study will be needed before control strategies can be developed. For example, the watershed above one sampling location, located on the North Fork of the Yuba River at the confluence with New Bullards Bar reservoir, contains seven separate mines or mine drainage sites, each of which has the potential to be a significant source of mercury. Additionally, because of the limited number of samples being collected at each site, estimation of seasonal effects may not be feasible.

Project Description

This project focuses on three important issues regarding mercury contamination within the Sacramento River watershed: ranking tributaries in terms of relative mass loads, estimating the impact of reservoirs on downstream water quality, and identification of areas of elevated bioaccumulation.

Data Collection

The data acquisition phase is expected to run from March, 1995, through January, 1996, and will include four components:

(1) **Main-stem water quality monitoring:** Cross-sectional composite grab samples will be collected from important tributaries of the Sacramento River just upstream of their points of confluence. These samples will be analyzed for total and dissolved mercury, as well as for TSS. Field measurements of pH, temperature, dissolved oxygen, and electrical conductivity will also be taken. Samples will be collected during winter storms, spring runoff, and late summer.

(2) **Input/output reservoir water quality monitoring:** Grab samples will be collected from the primary feeder streams of a Sierra reservoir just upstream of the reservoir. Grab samples will also be collected immediately downstream of the reservoir. These samples will be analyzed for total and dissolved mercury and methyl mercury, as well as for TSS. Field measurements of pH, temperature, dissolved oxygen (D.O.), and electrical conductivity (E.C.) will also be taken. Samples will be collected during winter storms, spring runoff, and late summer, and will be collected in coordination with the main-stem water quality monitoring component of the study.

(3) **Localized assessment of mercury in biota:** Multiple trophic levels of biota will be collected upstream, within, and immediately downstream of the reservoir from which water quality samples are collected. Tissue samples will be analyzed for total and methyl mercury. Samples will be collected during winter storms, spring runoff, and late summer, and will be collected in coordination the water quality monitoring component of the study.

(4) **Regional assessment of mercury in biota:** Multiple trophic levels of biota will be collected throughout the historical gold mining area of the Sierras. Tissue samples will be analyzed for total mercury. Samples will be collected during summer and fall.

This Quality Assurance Project Plan (QAPP) deals with the water quality monitoring portion of the study. A separate QAPP will be produced which deals with the biota sampling portion of the study.

Sampling and analysis methods capable of detecting mercury at levels below expected concentrations will be employed. Monitoring results will be used to rank main-stem rivers in terms of episodic mass loads, evaluate the effect of the reservoir studied on mercury transport and speciation, identify regional and localized areas of elevated mercury bioavailability and uptake, and evaluate possible control strategies. Most importantly, the information generated by the project will be used by the CVRWQCB in its TMDL process to further refine the mass emissions control strategy for mercury. A detailed description of this project is provided below.

Project Objectives

The objective of this project is to develop a proposed implementation plan for control of mercury from point and nonpoint sources within the Sacramento River watershed. This objective will be met by:

(1) using the results of the main-stem water quality monitoring and other available water quality data to rank main stem branches of the Sacramento River in terms of episodic mass loads;

(2) using the results of the input/output reservoir water quality monitoring to evaluate the effect of one reservoir on mercury transport and speciation within one watershed;

(3) using the results of the regional assessment of mercury in biota to rank watersheds in terms of bioavailable mercury;

(4) using the results of the localized assessment of mercury in biota to identify sources of bioavailable mercury within one watershed; and

(5) identifying and evaluating mercury control options for one watershed.

Measurements

On the main-stem river sites, cross-sectional composite grab samples will be analyzed for dissolved and total mercury, and suspended solids. At the reservoir input/output sites, grab samples will be analyzed for dissolved and total mercury, dissolved and total methyl mercury, and suspended solids. Temperature, pH, dissolved oxygen concentration, and electrical conductivity will be measured in the field at the time of sample collection. Data from existing gaging stations will be used to estimate flow rates at the time of sample collection.

Water Quality Criterion

The US EPA 4-day average criterion for total mercury concentration in fresh water for the protection of human health is 12 ng/l. (EPA, 1985)

Assessment Tools

This QAPP will be reviewed by the Technical Advisory Committee, by the State Water Resources Control Board Quality Assurance Officer, and by the U.S. EPA Quality Assurance Manager.

Routine quality assurance data will be reviewed by the QA Manager.

QA Reports will be reviewed by the Project Manager.

Schedule

The timing of water quality sampling is based on several considerations: (1) high stream flows re-suspend and transport the bulk of the sediment load (and associated trace element mass load) in rivers, (2) water column concentrations of many trace elements, including mercury, are highest during these periods, (3) the flow rates of streams within the Sacramento River watershed vary considerably within each year and from year to year, (4) flow rates within the watershed are controlled by meteorological conditions and by operation of an extensive set of water storage and conveyance facilities. For these reasons, water quality samples will be collected to characterize three important hydrologic conditions: winter storms, spring runoff, and low flow periods in late summer.

Water quality samples will be collected between March, 1995, and January, 1996. All water quality data will be validated by March, 1996. The implementation plan and final report for the project will be completed by October, 1996.

Project and Quality Records Required

Total and dissolved mercury concentrations, suspended solids concentration, pH, temperature, dissolved oxygen concentration, electrical conductivity, and flow rate data will be required for each sampling event. In addition, total and dissolved methyl mercury concentrations will be required for each sampling event associated with the reservoir input/output water quality sampling.

Quality records needed with mercury (and methyl mercury) analyses include those associated with samples submitted to the laboratory (field blank results, field duplicate results, blind spike results), and all relevant laboratory QC records (lab duplicates, matrix spikes, method blanks, standard reference materials.)

Quality records needed with suspended solids analyses include those associated with samples submitted to the laboratory (field blank results, field duplicate results, blind spike results), and all relevant laboratory QC records (i.e., lab duplicates.)

Quality records associated with pH, temperature, dissolved oxygen concentration, and electrical conductivity measurements taken in the field include records of proper equipment maintenance and calibration.

Quality records will not be required of flow rate data generated by other agencies.

Data Quality Objectives for Measurement Data

Water Quality Data Usage

For each main stem river sampling point, data from this project will be used to:

- Estimate instantaneous mass loads of total mercury, dissolved mercury, and particulate-associated mercury for each sampling event.

- Rank each tributary at its confluence in terms of mass load of total, dissolved, and particulate-associated mercury.

- Determine whether there is a significant correlation between mercury concentration and flow rate, or between mercury concentration and suspended solids concentration. A correlation will be considered significant at the 95% confidence level.

For the reservoir input/output sites, data from this project will be used to:

- Estimate instantaneous mass loads of total mercury, dissolved mercury, particulate-associated mercury, total methyl mercury, dissolved methyl mercury, and particulate-associated methyl mercury for each sampling event.

- Estimate changes in instantaneous mass loads into and out of the reservoir for total mercury, dissolved mercury, particulate-associated mercury, total methyl mercury, dissolved methyl mercury, and particulate-associated methyl mercury.

- Determine whether there is a significant correlation between mercury concentration and flow rate, or between mercury concentration and suspended solids concentration. A correlation will be considered significant at the 95% confidence level.

Scope of the Project

Domain (geographical, medium, time period)

The project will encompass sampling sites located within the lower Sacramento Valley, and within the watersheds of the Feather River and the Yuba River.

Ambient surface water will be measured.

The study period starts in March, 1995, and will continue through January, 1996.

Constraints on measurement project

The measurement project is constrained by the resources available to provide for field crews to visit each sampling site, and by the resources available to provide for analysis of all samples collected. An additional constraint on the project is the ability to gain access to all proposed sites during periods of high runoff. Not only do access conditions become more difficult during these times, but it is difficult to predict high flow events and therefore may be difficult to mobilize field crews to gather samples during periods of peak runoff.

Data needed

Total and dissolved mercury concentrations, suspended solids concentration, pH, temperature, dissolved oxygen concentration, electrical conductivity, and flow rate data will be required for each sampling event. In addition, total and dissolved methyl mercury concentrations will be required for each sampling event associated with the reservoir input/output water quality sampling.

Data uses

The data from this project will be used for:

- Estimation of instantaneous mass loads.
- Ranking sources of mercury within the watershed.
- Evaluating the impact of a reservoir on mercury mass loads and speciation.
- Estimation of correlation between flow, suspended solids, and mercury concentrations.

Decisions to be made

The data will be used to decide:

- Where significant sources of mercury are located.
- What control measures are appropriate.

Expected users of the data

The Central Valley Regional Water Quality Control Board will use results in their Total Maximum Daily Load process for heavy metals to develop a mercury control plan for the watershed.

Data Quality Objectives

The data quality objectives for this project are defined by the detection limits, precision, accuracy, and completeness associated with each type of measurement.

Detection Limits

Detection limits refer to the minimum concentration of a substance that can be measured and reported with 99% confidence that the analyte concentration is greater than zero.

Precision

Precision refers to the degree of agreement between individual measurements of a particular analyte from the same source. Precision is evaluated in terms of relative percent difference (RPD) between duplicate samples.

$$\text{RPD} = \frac{\text{difference between reported values}}{\text{average reported value}} \times 100\% \qquad (3)$$

In cases where the values measured are very close to the detection limit of the method used, it is more appropriate to evaluate precision by comparing the absolute difference between duplicate measurements (DIFF in Table 1) to the detection limit.

Accuracy

Accuracy refers to the degree of agreement of a measured value with the true or expected value of the analyte. Accuracy for mercury concentrations will be measured, using standard reference materials (SRMs) when available, as the percent recovery (REC) of the certified value.

$$\text{REC} = \frac{\text{reported value}}{\text{certified value}} \times 100\% \qquad (1)$$

When SRMs are not available, accuracy will be measured as recovery (REC) of spiked samples.

$$\text{REC} = \frac{\text{spiked sample value - sample value}}{\text{spike value}} \times 100\% \qquad (2)$$

For pH, D.O., E.C., and temperature measurements, accuracy will be measured as the difference (DIFF) from the "true" value of a reference material.

Completeness

Completeness is defined as the percentage of samples that are completely analyzed and determined to be valid.

The data quality objectives for the project are listed in Table 1.

Table 1. Data Quality Objectives

Measurement	Detection Limit	Precision	Accuracy	Completeness
Total and Dissolved Mercury Concentration	0.1 ng/L	Lab Dup RPD ≤ 25% or DIFF ≤ 0.1 ng/L Field Dup RPD ≤ 35% or DIFF ≤ 0.1 ng/L	SRM REC = 100% ± 25% Lab Spike REC = 100% ± 25% Blind Spike REC = 100% ± 30%	95%
Total and Dissolved Methyl Mercury Concentration	0.03 ng/L	Lab Dup RPD ≤ 25% or DIFF ≤ 0.03 ng/L Field Dup RPD ≤ 35% or DIFF ≤ 0.03 ng/L	SRM REC = 100% ± 25% Lab Spike REC = 100% ± 25%	95%
Total Suspended Solids Concentration	3 mg/L	Lab Dup RPD ≤ 10% or DIFF ≤ 3 mg/L Field Dup RPD ≤ 20% or DIFF ≤ 6 mg/L	Lab Control Standard REC = 100% ± 10%	95%
pH	n/a	n/a	DIFF ≤ 0.2 unit	95%
temperature	n/a	n/a	n/a	95%
dissolved oxygen	n/a	n/a	DIFF ≤ 0.2 mg/L	95%
electrical conductivity	n/a	n/a	DIFF ≤ 1% of range	95%

Notes: RPD = relative percent difference; REC = recovery; DIFF = absolute difference between duplicate measurements, or between expected and actual measurement.

Representativeness

There appear to be two limitations on the representativeness of the data that will be generated by this project. First, because samples associated with the reservoir input/output component of the study will be collected as near shore grabs, and because the parameters of interest may not be uniform throughout the stream cross section, measured values may deviate from values that would be obtained using cross-sectional flow-proportioned composite samples. Secondly, because flow conditions, suspended solids concentrations, and mercury concentrations may be extremely variable and unpredictable at some locations during the study period, grab sample values may deviate from values that would be obtained using flow-proportioned composite samples collected over a longer period.

While the limitations on representativeness mentioned above are acknowledged as important constraints to consider when evaluating the results of this study, this study is restricted to the specified sample collection methods by site accessibility constraints, practicality constraints, and the need to use ultra-clean sampling techniques.

Comparability

For mass-load rankings, main-stem tributaries will be sampled as cross-sectional composites just upstream of their confluence. At the confluence, each tributary will be sampled within one or two hours of the other. To the extent that each tributary is experiencing similar relative flow conditions at the time of sample collection, estimated mass load data can be used to rank each tributary in terms of mass load on an event-by-event basis.

Because all reservoir input/output data will be generated using the same sampling and analytical protocols, and will be collected within 8 hours of each other, the data collected can be used to compare event-by-event mass loads into and out of the reservoir studied.

It should be noted that data from the main-stem river sites will be generated using the same sampling and analytical protocols as those collected by the Sacramento Coordinated Water Quality Monitoring Program's Ambient Monitoring Program on the American and Sacramento rivers in the Sacramento urban area. Thus, data collected by this program at main-stem river sites will be directly comparable to data produced by the AMP.

Additionally, because the analytical methods used by this study are equivalent to methods recently used by the CVRWQCB (Conner, 1994), and because the sampling techniques will minimize contaminant-associated "noise," mercury concentration values from this project will be comparable to values generated by this and other programs using similar sampling and analytical protocols.

Documentation and Records

Data to include in a data report package

For each sample submitted, the contract laboratories shall provide to the Engineering Consultant the sample ID, the measured value of the constituent in question, the date of analysis, and the date of sample receipt. Additionally, the laboratories shall provide results from all laboratory QC procedures (blanks, duplicates, spikes, reference materials) associated with each sample batch, and the sample IDs associated with each batch.

Reporting Format

To aid the process of submitting data to the STORET system, results shall be reported in tabular format on electronic media according to the following format:

Columns	Content
1-15	Station number
16-21	Date (Format: YYMMDD)
22-25	Time (Military Format)
37-39	Depth of sample (in feet)
40-40	(blank)
41-41	Water type (S=surface)

42-42	(blank)
43-43	(blank for grab, "S" for cross-sectional composite grab)
44-47	(blank)
48-50	User ID (given by STORET system administrator)
65-65	Transaction type (A=add observation)
66-70	STORET parameter code
71-80	Data Value

Lab reporting turnaround time

Lab turnaround time for full lab reports for both mercury analyses and TSS analyses will be 4 weeks from sample receipt.

DATA ACQUISITION

Experimental Design

Type of Samples

All samples shall be grab samples collected using a peristaltic pump apparatus. Reservoir input/output sites will be collected by using a pole to extend the sample tubing as far as practical into the stream. Main-stem tributary sites will be sampled as cross-sectional spatial composites using the protocols (and sampling equipment) used by the Sacramento Coordinated Water Quality Monitoring Program's Ambient Monitoring Program (AMP).

Sampling Network Design, Rationale for the Design, and Guidelines for Selecting Sampling Points

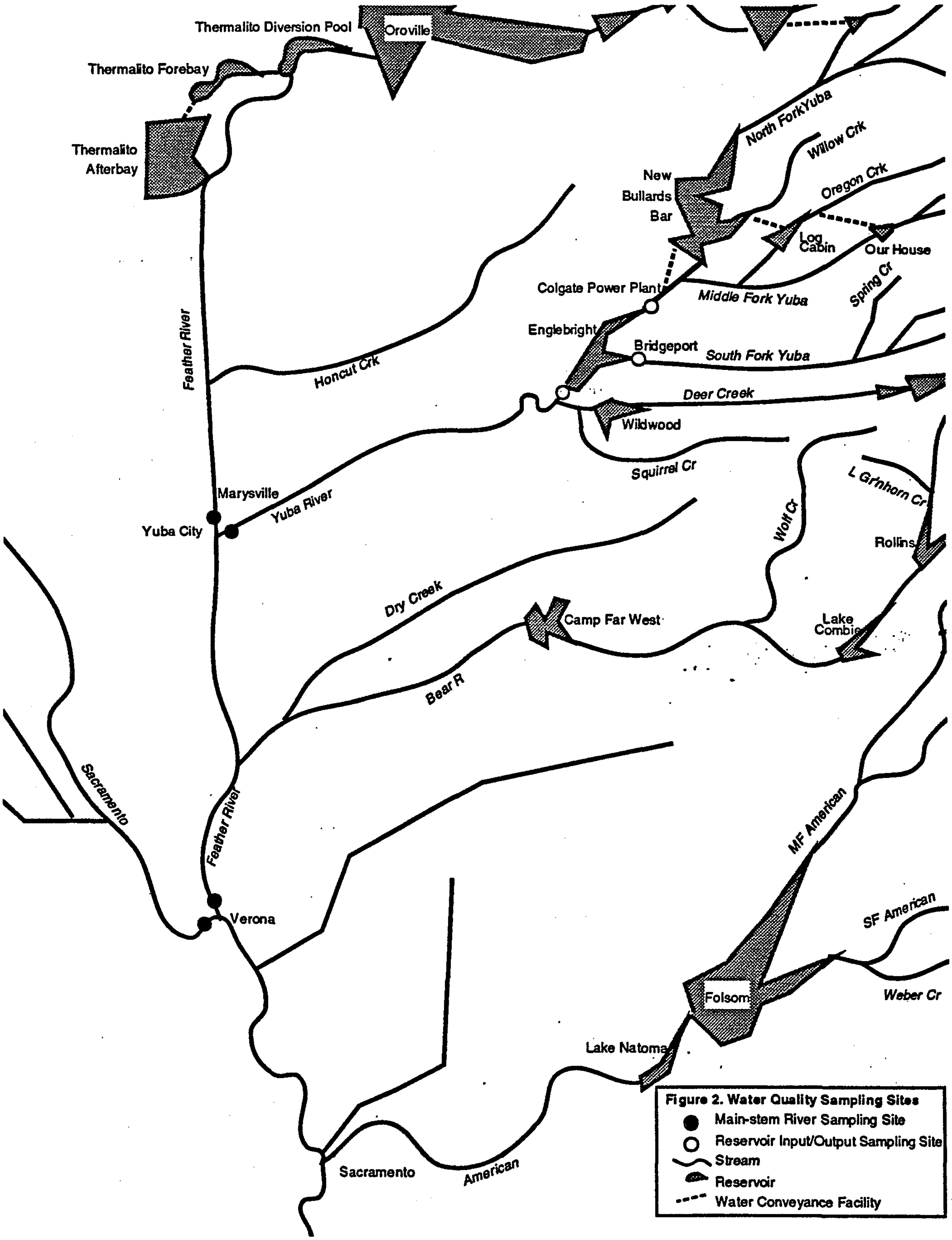
Water quality sampling sites were selected to rank tributaries in terms of relative mass loads, to estimate the impact of reservoirs on downstream water quality, and to support biota sampling which will be used to identify areas of elevated bioaccumulation.

<u>Main-stem water quality monitoring sites</u>

Four sampling sites were selected for the main-stem tributary component of the study. One pair of sites is located on the Sacramento River and the Feather River upstream of their confluence at Verona. Another pair of sites is located on the Feather River and the Yuba River upstream of their confluence at Yuba City/Marysville. See Figure 2. The rationale for the selection of these sites is to determine which tributary of the Sacramento River system carries the greater mercury mass load. The sampling sites immediately upstream of Verona were selected to determine if the upper Sacramento River or the Feather/Yuba/Bear tributary system contributes a greater mass load of mercury. The sampling sites immediately upstream of the Yuba/Feather confluence were selected to determine if the upper Feather River or the Yuba River contributes a greater mass load of mercury. Additionally, each of these sites provides a convenient location for launching the sampling vessel.

<u>Input/output reservoir water quality monitoring sites</u>

Englebright Reservoir was selected for study because the Yuba River has been identified as a significant source of mercury within the Sacramento River watershed, and because Englebright Reservoir is the last reservoir between the headwaters of the Yuba River and the Sacramento Valley floor. Therefore, this reservoir is expected to have a significant impact on mercury transport within the Sacramento River watershed and on downstream water quality.



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Englebright reservoir receives the bulk of its inflows from the North, South, and Middle Forks of the Yuba River. Except during high flow events, most of the flows in the Middle Fork are diverted to New Bullards Bar Reservoir, on the North Fork of the Yuba, before reaching Englebright Reservoir. See Figure 2. During normal operation, these flows, as well as flows from the North Fork, are then diverted through Colgate Power House before reaching Englebright Reservoir. During high flow events, spills from New Bullards Bar Reservoir merge with the North Fork of the Yuba River upstream of Colgate Power House.

Because Englebright Reservoir has two main inlets and one outlet, three sampling sites were selected for the reservoir input/output component of the study. One site is located on the Middle Fork of the Yuba River immediately downstream of the Colgate Power Plant. Another site is located on the South Fork of the Yuba River at Bridgeport. The third site is located on Yuba River just downstream of Englebright Dam and its associated hydro-electric generating facilities. See Figure 2. These sites were selected to determine mass loads into and out of Englebright Lake, and to measure associated changes in water quality upstream and downstream of the reservoir. Guidelines for selecting these sites included the ability to sample all the important inputs and outputs of the reservoir, that the influence of unmeasured inputs be minimized, and that each site be accessible during adverse weather conditions.

The site on the Middle Fork of the Yuba River below Colgate Power Plant was selected because the majority of the flow from the North Fork of the Yuba River enters the Middle Fork (and Englebright lake) via the Colgate Power Plant. The site on the South Fork of the Yuba River at Bridgeport was selected because it is the last easily accessible site on the South Fork of the Yuba River before it enters Englebright Lake. The site located on Yuba River just downstream of Englebright Dam was selected because it is located upstream of other streams (i.e., Deer Creek) that may contribute significant mass loads of mercury on a seasonal basis.

Coordination with biota sampling sites

Many locations within the Yuba River watershed exhibit high levels of bioaccumulation (Slotton, 1995). As part of this project, multiple trophic levels of biota will be sampled from numerous sites within the Yuba River watershed upstream of Englebright Reservoir to determine levels of bioaccumulation. Biota samples will also be collected from the input/output reservoir water quality monitoring sites. Water quality data collected from these sites will be used to explore relationships between water quality and bioaccumulation, and to explore the impact of the reservoir on these relationships.

Sampling Schedule/Frequency

Three sets of water quality samples will be collected during spring runoff. Sampling will be scheduled to the extent feasible to coincide with early, peak, and late spring runoff conditions. Samples will be collected between April and July, 1995.

Two sets of water quality samples will be collected during low flow periods in late summer and early fall. Samples will be collected between August and October, 1995.

Two sets of water quality samples will be collected during high flow periods associated with winter storms. If feasible, and if winter conditions continue, a winter storm will be sampled in March, 1995. One or two winter storm samples will be collected between November, 1995, and January, 1996.

To assess short-term temporal variability of mercury and suspended solids concentrations, a short-term variability assessment will be conducted at one main-stem river site and at one reservoir input site during the study period. Three samples will be collected at each site during each of these studies. The timing of sample collection will be such that subsequent samples will be separated by approximately one hour.

Sample Matrices

All samples shall be of fresh surface water.

Measurement Parameters of Interest

Total mercury and methyl mercury concentrations and their dissolved fractions, suspended solids concentrations, and flow rates are of critical importance. Temperature, dissolved oxygen, electrical conductivity and pH values are of non-critical importance.

Guidelines for Selecting Sampling Equipment

Grab samples shall be collected using peristaltic pumps. This method was selected because it results in low mercury contamination, while still allowing for both cross-sectional sampling and pole-mounted near-shore grab sampling.

Sampling Methods Requirements - Reservoir Input/Output Sites

At reservoir input and output sites, water quality samples will be collected as near-shore grabs, using a peristaltic pump apparatus. During sampling, a pole will be used to extend the intake end of the sample tubing into the stream. Specific sampling procedures are described below.

<u>Total and Dissolved Mercury and Methyl Mercury</u>

The following sections describe the standard operation procedure (SOP) for grab sample collection of samples for total and dissolved mercury and methyl mercury analysis.

<u>Materials Needed</u>

Sample collection bottles will be Teflon (FEP or PFA), 250 mL. Two sample bottles are filled at each sampling location. A peristaltic pump will be used for sample collection. Medical grade silastic tubing (1/2-inch ID) is used for the pump tubing. Suction tubing will be Bev-A-Line®IV (polyethylene liner with ethyl vinyl acetate shell). On the suction side of the pump, the tubing is taped to a fiberglass pole that is used to extend the tubing over the sampling location. On the pressure side of the pump, the tubing is attached to a ring stand with clamps to hold the tubing over the sample bottle.

<u>Decontamination</u>

New bottles are cleaned by heating to 65-75°C in 4 N HCl for at least 48 hours. The bottles are cooled, rinsed 3 times with ultra-clean water, and then filled with ultra-clean water containing 1% HCl. These bottles are capped and placed in a clean oven at 60-70°C overnight. After cooling, they are rinsed 3 more times, filled with ultra-pure water plus 0.4% (v/v) HCl, and placed in a mercury-free class 100 clean-air station until the exterior is dry. The bottles are then tightly capped (with a wrench) and double bagged in new polyethylene zipper bags until needed. After the initial cleaning, bottles are cleaned as above, except with only 6-12 hours in the hot 4 N HCl step.

Sample Collection

Grab samples will be collected according to the method described below.

Prior to sample collection, the pump tubing is flushed with several volumes of sample water.

1. At least two persons, wearing fresh clean-room gloves at all times, are required on a sampling crew.
2. One person ("dirty hands') pulls a bagged bottle from the box and opens the outer, dirty bag, avoiding touching inside that bag.
3. The other person ("clean hands") reaches in, opens the inner bag, and pulls out the sample bottle.
4. This bottle is opened, and the acidified water is discarded.
5. The bottle is then placed on or by the ring stand directly beneath the pump tubing. At no time should the pump tubing touch the sample bottle. The sample bottle is then completely filled with sample water. The bottle is then capped and checked for air bubbles.
6. The bottle is re-bagged in the opposite order from which it was removed.
7. Clean room gloves are changed between samples and whenever something not known to be clean is touched.

Field Blank Collection

Field blanks will be collected using two 2.5-liter jugs of mercury free water according to the method described below.

1. Soak end of sample tubing for 3 minutes in acidified water in standard teflon sample bottle.
2. Insert clean sample tubing a short distance into the first jug of DI water.
3. Pump forward. Pump entire contents of first jug. Never insert tube more than a small distance into the blank water.
4. Insert clean sample tubing a short distance into the second jug of DI water.
5. Pump forward. Obtain blank sample from the last half of the water contained in the second jug.

Preservation

Samples are immediately cooled to 4°C and remain at this temperature until analyzed. Samples are delivered to the laboratory within 28 hours of sample collection.

Following receipt by the laboratory, samples requiring analysis for dissolved mercury or dissolved methyl mercury are filtered through a 0.2μ filter, using ultra-clean handling. All samples are then preserved as follows:

- For samples requiring both mercury and methyl mercury analysis, high purity HCl (0.5% v/v) is added to the samples in the laboratory within 48 hours of sample collection. After standing overnight, a 45 ml aliquot of the sample is dispensed for methyl mercury analysis. The remaining sample is then oxidized with 1% BrCl and allowed to stand overnight before analyzing for mercury.
- For samples requiring only mercury analysis, high purity 0.2 N BrCl in 12 N HCl (1.0% v/v) is added to the samples in the laboratory within 48 hours of sample collection. The sample is then allowed to stand overnight before analyzing for mercury.

Holding Times

Samples will be analyzed within 60 days of sample collection.

Performance Requirements

This sample collection technique requires (1) that the sample bottle and lid come in contact only with surfaces known to be clean, or with the sample water; and (2) that no air bubbles are present in the bottle immediately following sample collection.

What to do if a Failure Occurs

If the performance requirements listed above are not met, the sample will be re-collected. If contamination is suspected, the sample will be collected using a fresh sample bottle. If an air bubble is present, additional sample will be collected into the same bottle.

Responsibility for Corrective Action

It is the shared responsibility of all members of the field crew to determine if the performance requirements have been met and to collect an additional sample if required.

Suspended Solids

The following sections describe the standard operation procedure (SOP) for grab sample collection of samples for total suspended solids (TSS) analysis.

Materials Needed

Samples for TSS analysis will be collected into 500 ml polyethylene bottles. The same pumping apparatus used for the mercury sampling will be used for TSS.

Decontamination

Sample bottles are cleaned by the manufacturer.

Sample Collection

Samples for TSS analysis shall be collected following collection of samples for mercury analysis. Water samples are obtained using the pump apparatus as described in the mercury sample collection procedure. The bottle is filled to the shoulder with sample water, and then capped.

Field Blank Collection

Field blanks will be collected according to the above methods except that the pump tubing and the bottle will be rinsed once with purified water supplied by the laboratory, then filled with this same water.

Holding Times

Maximum holding time is 7 days from time of sample collection.

Preservation

Samples are immediately cooled to 4°C and remain at this temperature until analyzed.

Performance Requirements

Samples are to be collected from the same location that mercury samples were collected. The sampler should take precautions not to agitate bottom sediments upstream of the sample bottle. Material found floating on the surface of the water must not enter the sample container.

What to do if a Failure Occurs

The sample shall be recollected using the same sample bottle.

Responsibility for Corrective Action

It is the shared responsibility of all members of the field crew to determine if the performance requirements have been met and to collect an additional sample if required.

Sampling Methods Requirements - Main-stem Tributary Sites

At the main-stem tributary sites cross-sectional spatial composite samples are collected. The schematic in Figure 3 shows the general approach used to collect sample aliquots. For each composite collected, grab samples are collected from sampling "verticals" which are equally spaced across the surface of the river. At each of these "verticals," water is collected at three depths. These depths are 1/6, 1/2, and 5/6 of the total distance from the surface of the river to the bottom.

Cross-sectional Composite Sample

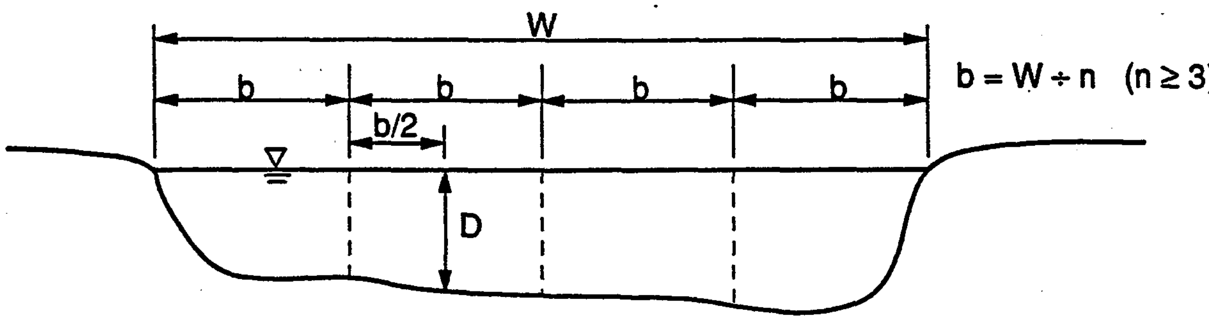
The following sections describe the standard operation procedure (SOP) for cross-sectional composite sample collection.

Materials Needed

A peristaltic pump will be used for sample collection. Medical grade silastic tubing (1/2-inch ID) is used for the pump tubing. Suction tubing will be Bev-A-Line®IV (polyethylene liner with ethyl vinyl acetate shell). A fiberglass pole is attached to the suction side of the pump tubing and is used to extend the tubing over the sampling location. A 10-liter high density polyethylene carboy is used to collect the composite sample. The pressure side of the pump tubing is placed in a vented filler cap placed on the top of the carboy. To collect the samples at the different depths, the pump tubing is attached to a weighted sampling apparatus. The weighted sampling apparatus is constructed so that the suction tubing extends into the direction of flow and so that the sampled water does not come in contact with any portion of the sample apparatus other than the suction tubing.

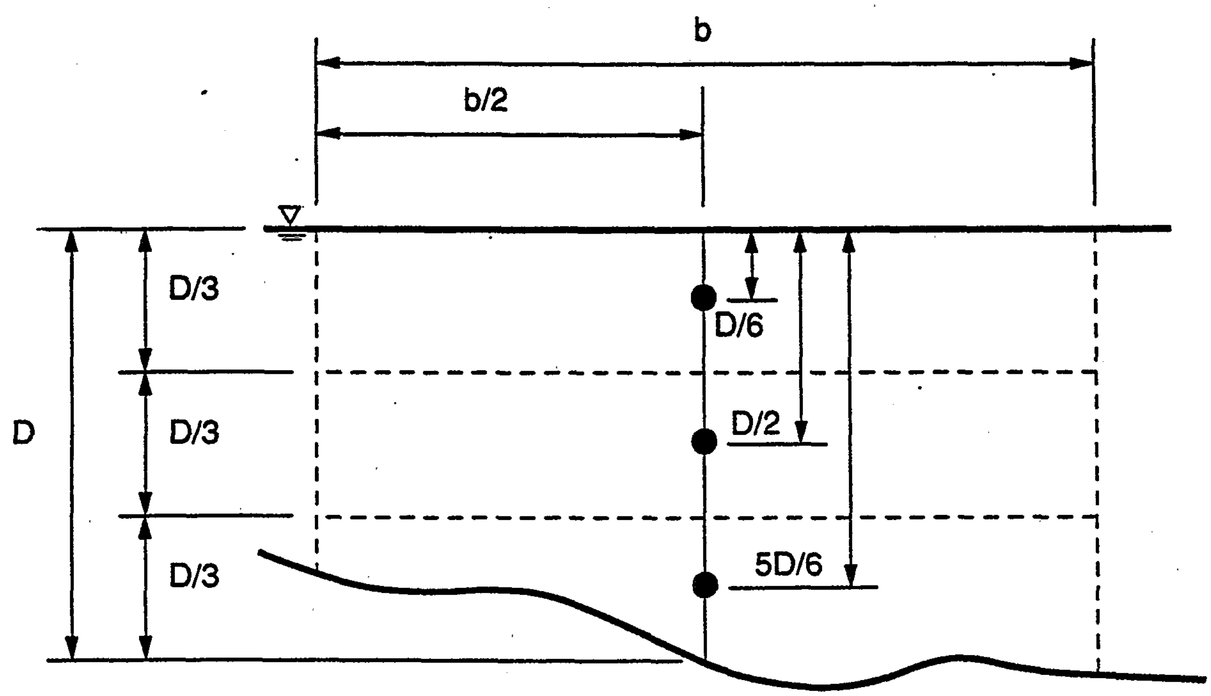
Figure 3: Sampling points for cross-sectional composite sampling

Step 1. Divide the top of the river into partitions of equal width.



Step 2. Establish vertical transects at the midpoint of each partition.

Step 3. Measure the depth at each vertical transect.



Step 4. Draw samples from the vertical transect at depths of 1/6, 1/2, and 5/6 the total depth.

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Decontamination

Carboys, closed caps, and filler caps are cleaned by rinsing with D.I. water five times, soaking in 1:1 nitric acid overnight, and rinsing again five times with D.I. water and one time with Super Q water. After cleaning, carboys are capped with their regular caps and the filler caps are stored in acid rinsed ziplock bags. Pump tubing is cleaned by filling tubing with 2 N nitric acid for 1 week followed by rinsing and filling with Milli-Q water for 1 week and finally rinsing three to four times with Milli-Q water. The tubing is then stored in acid-cleaned bags until ready for use.

Sample Collection

Prior to sample collection, approximately 10 liters of river water at the sampling location is pumped into the carboy through the tubing and filler cap. This water is used to completely rinse the carboy. Approximately 1 liter of water is decanted through the carboy spigot and the rest is poured out the top of the carboy. Prior to the collection of each aliquot, the tubing is flushed at least once with site water. An equal volume of sample is collected from each point on the cross-section. Upon full collection of the composite sample, the sample is then shaken and decanted into the sample bottles.

Total and Dissolved Mercury

The SOP for collection of main stem tributary samples for total and dissolved mercury analysis is the same as described above for the collection of the reservoir input/output mercury samples with the following exception. Instead of collecting the sample from the river through the pump, the sample is decanted from the carboy into the sample bottles. The carboy is shaken prior to filling each of the bottles to keep the sample well mixed.

Suspended Solids

The SOP for collection of main stem tributary samples for suspended solids analysis is the same as described above for the collection of the reservoir input/output TSS samples with the following exception. Instead of collecting the sample from the river through the pump, the sample is decanted from the carboy into the sample bottles. The carboy is shaken prior to filling each of the bottles to keep the sample well mixed.

Data Collection Procedures - Dissolved Oxygen, pH, Temperature and Electrical Conductivity

Field measurements of dissolved oxygen concentration, pH, temperature, and electrical conductivity will be made at the time that all samples are collected.

Materials Needed

A meter and sensors (Hydrolab DataSonde 3 Submersible Multiparameter Water Quality Datalogger) will be used to measure temperature, D.O., pH and E.C.

Implementation

Temperature, pH, D.O. and E.C. measurements are made *in situ* at the sampling location. Each parameter is measured at one location at the reservoir sampling sites. Each parameter is measured at each vertical for the mainstem tributary sites.

Performance Requirements

Measurements for temperature, pH, D.O., and E.C. shall be made when the instrument is immersed in site water and after sufficient time has passed for readings to stabilize.

What to do if a Failure Occurs

If the duplicate measurements of the parameters do not meet performance requirements, the measurements should be repeated.

Responsibility for Corrective Action

It is the shared responsibility of all members of the field crew to determine if the performance requirements have been met and to repeat the appropriate measurement if required.

Sample Handling and Custody Requirements

Field Log

Field crews shall be required to keep a field log throughout each sampling run. For each sampling event, the following items shall be recorded:

- Time of sample collection.
- Etched ID number on mercury sample bottles used.
- Sample IDs assigned to TSS and mercury samples (including duplicates, triplicates, and field blanks).
- Temperature, D.O., E.C., and pH measurements.
- Water color, weather conditions, and a subjective evaluation of flow conditions at time of sample collection.
- Any unusual occurrences associated with the sampling event.

For each sampling run, field crews shall record the following items:

- Date and time of temperature, D.O., E.C., and pH probe calibration.
- Condition of sampling containers upon receipt.
- Date and time of sample container receipt and sample delivery to shipping office or laboratory.

Appropriate pages from the field log shall be photo-copied and delivered to the project manager at the conclusion of each sampling run.

Lab custody log

Laboratories shall maintain lab custody logs sufficient to track each sample submitted and to analyze or preserve each sample within the holding times specified.

Examples of sample documentation forms

Examples of sample labels, and chain of custody (COC) forms are shown in Figures 4 and 5.

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Anlab Client Code: ______ **CHAIN OF CUSTODY RECORD** Page ____ of ____

Anlab

ANALYTICAL LABORATORY

1910 "S" STREET • SACRAMENTO, CA 95814
(916) 447-2946 • FAX (916) 447-8321

CLIENT INFORMATION		
Company:	Contact Name:	
Address:		
City:	State:	Zip:
Billing Address:		
Telephone:	FAX:	
P.O. Number:	Project Name:	
Sampler's Name:	Sampler's Co.:	

Anlab Use Only:

Hours: ______
Miles: ______
Equip.: ______

			ANALYSIS ➤										Sample Type					Number of Containers					Preservation		
SAMPLE IDENTIFICATION	Date	Time											W	WW	SOIL	SLUDGE		PLASTIC	GLASS	VOA	STERILE		TEMP	ACID	BASE

COMMENTS/SPECIAL INSTRUCTIONS:

TURNAROUND TIME:
24 HOUR [ ] 48 HOUR [ ] 72 HOUR [ ]
5 DAY [ ] STANDARD [ ]

SAMPLE DISPOSAL: [ ] HOLD [ ] RETURN [ ] DISPOSE

SHIPPED VIA: [ ] UPS [ ] FED-EX [ ] BUS

SAMPLE RELINQUISHED BY	PRINT NAME/COMPANY	DATE/TIME	RECEIVED BY	PRINT NAME/COMPANY

ANLAB WILL PERFORM THE SERVICES IN ACCORDANCE WITH THE NORMAL STANDARD OF WORKMANSHIP IN THE PROFESSION. THE TOTAL LIABILITY OF ANLAB, ITS OFFICERS, AGENTS, EMPLOYEES OR SUCCESSORS, TO THE CLIENT, SHALL NOT EXCEED THE INVOICED AMOUNT FOR SAID SERVICES. CLIENTS' ACCEPTANCE OF A WORK ORDER AND/OR PROPOSAL RELEASES ANLAB FROM ANY LIABILITY IN EXCESS OF THE INVOICED AMOUNT FOR THE SERVICES, NOTWITHSTANDING ANY PROVISION TO THE CONTRARY IN ANY CLIENT PURCHASE ORDER OR CONTRACT.

All hazardous waste samples will be returned to client or billed for disposal.

Figure 4. Example COC form

C-035669

Figure 5. Example bottle label

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1910 S STREET, SACRAMENTO, CA 95814

NO. ____________________

Lab Use: Sample Type: ____________________
____
____

CUSTOMER NAME ____________________
DATE & TIME SAMPLED ____________________
PERSON SAMPLING ____________________
PERSON DELIVERING SAMPLE ____________________
SAMPLING POINT ____________________

Labeling Procedures

Mercury and Methyl Mercury Samples

The bottles used for collecting samples for mercury analysis will be etched with bottle numbers supplied by the laboratory. No labels will be applied to the bottles.

Suspended Solids Samples

Samples collected for TSS analysis will be labelled using the example sample label shown in Figure 5 as follows:

- **No.** (not used)
- Lab Use: Sample Type: TSS, grab
- Customer Name: LWA
- Date & Time Sampled: mm/dd/yy hh:mm (24 hour clock)
- Person Sampling: Last Name, First initial
- Person Delivering Sample: Last Name, First initial
- Sampling Point: Name of sample site

Procedures for transferring and maintaining custody

Field crews shall have custody of samples during field sampling. Chain of custody forms shall accompany all samples during shipment to contract laboratories. Temperature, D.O., E.C., and pH measurements taken at the time of sample collection shall be recorded on the COCs for use by the analysts.

Analytical Methods Requirements

Method - Mercury Analysis

For total mercury analysis, samples are wet-oxidized using BrCl (Bloom and Creceilius, 1983). Following oxidation, samples are pre-reduced with $NH_2OH \bullet HCl$ and then further reduced with $SnCl_2$ and purged onto gold traps with purified nitrogen.

The gold traps are then heated and the mercury desorbed into inert carrier gas (ultra-pure argon or helium) for detection by cold-vapor atomic fluorescence spectroscopy (CVAFS) (Bloom and Fitzgerald, 1988). The excitation source is a 4-W low pressure mercury vapor lamp, emitting predominantly at 254 nm, and the detector is a UV-visible general purpose photomultiplier shielded from stray light with a 253.7 nm interference filter. Atomic fluorescence is monitored at 90° to the direction of the excitation beam, through a 10-mm square fluorescence cell.

Total methyl mercury is determined using aqueous phase ethylation to generate a volatile methyl ethylmercury derivative of methyl mercury in the sample. This compound is then chromatographed by cryogenic gas chromatography, pyrolytically broken down to elemental mercury and detected using CVAFS as described above for mercury analysis.

Dissolved fractions are determined by first clean filtering each sample through a 0.2µ filter, and then conducting the analyses described above.

Method - Suspended Solids Analysis

Total suspended solids concentrations shall be carried out using the standard operating procedures EPA method 160.2 (EPA, 1983.)

Performance Requirements

Table 2 summarizes the quality control procedures and the related acceptance criteria employed in the project.

All samples shall be analyzed using standard operating procedures. Any deviation from these procedures shall be considered a failure to meet performance requirements. Additionally, failure to meet the data acceptance criteria listed in Table 2 for laboratory generated QC samples shall be considered a failure to meet performance requirements.

What to do if a Failure Occurs

If a failure occurs, the analytical equipment shall be checked, repaired, and re-calibrated if necessary. Affected samples shall be re-analyzed.

Responsibility for Corrective Action

It is the responsibility of the contract laboratory to perform these corrective actions.

Quality Control Requirements

The quality control procedures used in the laboratory and in the field, the frequency and acceptance criteria, and corrective actions to be taken are presented below in Table 2.

Table 2. Quality control procedures, frequency, and acceptance criteria.

Measurement	QC Procedure	Frequency	Acceptance Criteria	Corrective Action
Mercury DL = 0.1 ng/L	Lab duplicate	1 per 20 samples	RPD ≤ 25% or DIFF ≤ 1 DL	recalibrate and/or reanalyze both samples
	Lab Spike	1 per 20 samples	REC = 100% ± 25%	recalibrate and/or reanalyze
	Method Blank	3 per analytical batch	n/a (results are blank-corrected)	n/a
	Standard Reference Material	1 per 20 samples	REC = 100% ± 25%	recalibrate and/or reanalyze
	Field Blank	1 per sampling run	Reservoir Sites: Blank < 1.0 ng/L River Sites: Blank < 2.5 ng/L	Examine field log. Re-train sampling crew. Qualify data as needed.
	Blind Spike (spiked at 3 to 5 time ambient levels)	1 per 25 samples	REC = 100% ± 30%	recalibrate and/or reanalyze
	Field Duplicate	1 per sampling run	RPD ≤ 35%	reanalyze both samples and increase frequency of field duplicates
Methyl Mercury DL = 0.03 ng/L	Lab duplicate	1 per 20 samples	RPD ≤ 25% or DIFF ≤ 1 DL	recalibrate and/or reanalyze both samples
	Lab Spike	1 per 20 samples	REC = 100% ± 25%	recalibrate and/or reanalyze
	Method Blank	3 per analytical batch	n/a (results are blank-corrected)	n/a
	Standard Reference Material	1 per 20 samples	REC = 100% ± 25%	recalibrate and/or reanalyze
	Field Blank	1 per sampling run	Blank < 0.20 ng/L	Examine field log. Re-train sampling crew. Qualify data as needed.
	Field Duplicate	1 per sampling run	RPD ≤ 35%	reanalyze both samples and increase frequency of field duplicates
Suspended Solids DL = 3 mg/L	Lab duplicate	1 per 10 samples	RPD ≤ 10% or DIFF < 3 mg/L	reanalyze both samples
	Method Blank	1 per 20 samples	Blank < 3 mg/L	reanalyze all samples in batch
	Lab Control Standard	1 per 20 samples	REC = 100% ± 10%	reanalyze all samples in batch
	Field Blank	1 per sampling run	Blank < 3 mg/L	Examine field log. Re-train sampling crew. Qualify data as needed.
	Field Duplicate	1 per sampling run	RPD ≤ 20% or DIFF < 6 mg/L	reanalyze both samples
pH	Check standard solution	1 per sampling event	DIFF ≤ 0.2 unit	recalibrate
D.O.	Check standard solution	1 per sampling event	DIFF ≤ 0.2 mg/L	recalibrate
E.C.	Check standard solution	1 per sampling event	DIFF ≤ 1% of range	recalibrate

Notes: RPD = relative percent difference; REC = recovery; DIFF = absolute difference between duplicate measurements, or between expected and actual measurement.

Instrument/Equipment Testing, Inspection, and Maintenance Requirements

Field Equipment

The DataSonde 3 Multiparameter Datalogger is maintained according to the manufacturer's specifications as described in the owner's manual.

Lab Equipment

Frontier Geosciences

Frontier Geosciences' lab equipment is tested, inspected, and maintained as described in their quality assurance manual (see Appendix A).

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Balances and reference weights used are certified annually against NIST standards.

Instrument Calibration and Frequency

Field Equipment

The DataSonde 3 Multiparameter Datalogger is calibrated as described in the owner's manual. Temperature calibration is factory-set and requires no recalibration. pH is calibrated using standard buffer solutions. Dissolved oxygen is calibrated against a water sample saturated with dissolved oxygen. E.C. is calibrated using potassium chloride (KCl) standard solutions.

Lab Equipment

Frontier Geosciences

Frontier Geosciences' lab equipment is calibrated as described in their quality assurance manual (see Appendix A).

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Balances are calibrated daily using the certified reference weights.

Data Acquisition Requirements (Non-direct Measurements)

Flow data collected by other agencies within the study area will also be used in this study. For this reason, this study will be relying upon data with an unknown level of uncertainty.

Because flow values will be used along with mercury concentration data and TSS data to estimate correlations and mass loads, it is desirable that the uncertainty associated with flow data be less than or equal to the uncertainty associated with mercury and TSS data. Because the allowable variability between field duplicates for total mercury analysis is ± 35%, flow measurements should meet this same requirement.

However, because the technology associated with flow measurement is well proven, and because each of the agencies that gathers flow data performs its own quality control procedures, the overall uncertainty of the data is expected to be less than that associated with chemical analyses.

Data Management

Copies of field logs, copies of chain of custody forms, preliminary and final lab reports, and electronic media reports will be sent to the Engineering Consultant. Each type of report will be stored in a separate file folder and will be ordered chronologically. Original copies of field logs will remain with the Engineering Consultant when not in use by the field crew. Original chain of custody forms, and copies of the preliminary and final data reports shall be kept by the Contract Laboratories.

Data will be transferred to a personal computer in the office of the Engineering Consultant. Checks will be performed following every data entry or data transfer procedure to determine if any data transcription errors occurred.

Correlations between flow and TSS or mercury concentrations shall be computed using a standard statistical analysis software package.

The instantaneous mass loads that are estimated for the main-stem river sites will be ranked for each pair of sites using paired t-tests. Instantaneous mass loads and changes in instantaneous mass loads that are estimated for the reservoir input/output sites will also be compared and ranked using paired t-tests. If a significant correlation is seen between mercury concentrations and flow rate, then a flow history during the study period may be compiled.

ASSESSMENT

Assessment and Response Actions

Assessments of compliance with quality control procedures will be undertaken on a routine basis during the data collection phase of the project.

Performance assessments of sampling procedures will be performed by field sampling crews. Corrective actions shall be carried out by field sampling crews and shall be reported to the Engineering Consultant.

Assessment of laboratory QC results and implementation of corrective actions will be the responsibility of the QA officer at each laboratory and shall be reported to the Engineering Consultant.

Assessment of field QC results and implementation of corrective actions shall be the responsibility of the Engineering Consultant.

Routine procedures to assess precision and accuracy, criteria for success, and response actions, are listed in Table 2.

QA Reports to Management

Following review of results from each sampling run, the Engineering Consultant shall provide to the Quality Assurance Manager a Quality Assurance Report which summarizes the status of the project, results of performance evaluations and system audits, results of periodic data quality assessments, and significant QA problems associated with the sampling run and recommended solutions. On a quarterly basis, these reports will be summarized and sent to the Project Manager and the State Water Resources Control Board Contract Manager as part of the normal quarterly status reports.

DATA REDUCTION, VALIDATION, REPORTING AND USABILITY

Reduction

Suspended solids concentrations shall be calculated according to the following formula:

$$TSS\ [mg/L] = \frac{(\text{Wt after drying @ } 105°C\ [mg] - \text{Tare Wt } [mg]) \pm \text{Blank } [mg]}{\text{ml of sample}} \times 1000$$

Blank correction for suspended solids measurements shall be performed only if the difference between the weights before and after drying is greater than or equal to 0.5 mg.

Mercury and methyl mercury concentrations shall be calculated as set forth in the QA Manual for Frontier Geosciences (Appendix A). The values reported shall be corrected for method blank or reagent blank concentrations.

Validation

The Data quality objectives listed in Table 2, in addition to standard data validation procedures set forth in each laboratory's QA Manual, shall be used to accept, reject, or qualify the data generated by each lab. Each laboratory QA Officer shall be responsible for validating data generated from each lab. The Engineering Consultant shall be responsible for validating and qualifying all data based on evaluation of field and lab QC samples.

Reporting

The Engineering Consultant shall prepare and submit all water quality-related data generated by the project to the State Board for input into the SWQIS/STORET system. Data shall be submitted to the State Board Information Services Office on computer diskette or on forms provided by the State Board. The Engineering Consultant shall be responsible for verification of data quality of all such media.

In cases where field blank results exceed the acceptance criteria listed in Table 2, data collected during the sample run associated with the unacceptable field blank shall be qualified and reported as follows:

- If the environmental sample concentration is equal to or greater than 5 times the field blank level, the measured concentration shall be reported with no modification. (e.g., If the field blank equals 1.5 ng/L, then a measured concentration of 8.0 ng/L would be reported as "8.0 ng/L.")

- If the environmental sample concentration is less than 5 times the field blank level, the measured concentration shall be reported as being "less than" the measured concentration. (e.g., If the total mercury field blank equals 1.5 ng/L, then a measured concentration of 4.0 ng/L would be reported as "<4.0 ng/L.")

Usability

Data that meet the data quality objectives of Table 2 shall be considered usable for purposes of this study. It shall be the responsibility of the Engineering Consultant to resolve any issues related to data quality and to provide an estimate of uncertainty associated with unverified data.

REFERENCES

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Sacramento River Mercury Control Planning Project

Quality Assurance Project Plan

November, 1995

Prepared by

Darell G. Slotton,
Division of Environmental Studies
University of California, Davis

for the
Sacramento Regional County Sanitation District

PROJECT MANAGEMENT

Title and Approval Sheet

QUALITY ASSURANCE PROJECT PLAN FOR THE <u>BIOTA MERCURY SAMPLING PORTION</u> OF THE SACRAMENTO RIVER MERCURY CONTROL PLANNING PROJECT

Implemented by the Sacramento Regional County Sanitation District

prepared by

Darell G. Slotton

Division of Environmental Studies
University of California, Davis

Approvals:

	Cheryl Creson	4/24/96
Project Manager	Cheryl Creson, Water Quality Division Chief, SRCSD	Date
	Armand Ruby III	4/8/96
QA Manager	Armand Ruby, Senior Environmental Scientist, Larry Walker Assoc.	Date
	Greg Frantz	4/22/96
State Board Contract Manager	Greg Frantz, California State Water Resources Control Board	Date

CONTENTS

FIGURES

TABLES

Distribution List

Cheryl Creson, SRCSD

Greg Frantz, SWRCB

Bill Croyle, CVRWQCB

Technical Advisory Committee:

- Dick Zembec, US Forest Service (USFS)
- Jerry Miller, Desert Research Institute
- Rick Humphreys, State Water Resources Control Board
- Ron Churchill, Division of Mines and Geology
- Sean Hogan, USEPA - Region 9
- Chris Stathos, Mother Lode Skin Diving Shops
- Peter Richerson , UC Davis
- Dave Sbaffi, Cal Sierra Development Company
- Michael Pickering, Brush Creek Mining and Development Co.
- Steve Swarzbach, U.S. Fish and Wildlife Service
- David Crane, California Dept. of Fish and Game
- Don Porcella, Electric Power Research Institute
- Joseph Domagalski, USGS

Project Organization and Responsibility

This project will be managed by the Sacramento Regional County Sanitation District (SRCSD). The project manager from the SRCSD is Ms. Cheryl Creson. She is currently Chief of Sacramento County's Water Quality Division.

The project quality assurance manager will be Armand Ruby, Senior Environmental Scientist with Larry Walker Associates.

Sample collection and other data acquisition work will be conducted by U.C. Davis, sub-contracting to the Engineering Consultant, Larry Walker Associates (LWA), an engineering firm located in Davis, California.

Analysis of biota samples for total mercury concentrations will be carried out by Darell Slotton and Shaun Ayers at Slotton's U.C. Davis mercury laboratory.

Analysis of biota samples for methyl mercury concentrations will be carried out by Frontier Geosciences, an analytical laboratory located in Seattle, Washington.

The principal data user and decision-maker for this project will be the Central Valley Regional Water Quality Control Board (CVRWQCB). This state agency will be responsible for incorporating mass load estimates and proposed control measures into its Mass Emissions Strategy for heavy metals in the Sacramento River watershed.

A technical advisory committee (TAC), consisting of staff from the SRCSD, the State Water Resources Control Board (SWRCB), the Central Valley Regional Water Quality Control Board, the U.S. Forest Service, the U.S. Fish and Wildlife Service, the Desert Research Institute, the California Division of Mines and Geology, the California Department of Fish and Game, the University of California at Davis, U.S. EPA Region IX, U. S. Geological Survey, and commercial and recreational mining interests will serve as technical reviewers for the project. The TAC will review this QAPP and the final project report.

The organizational structure is shown in Figure 1.

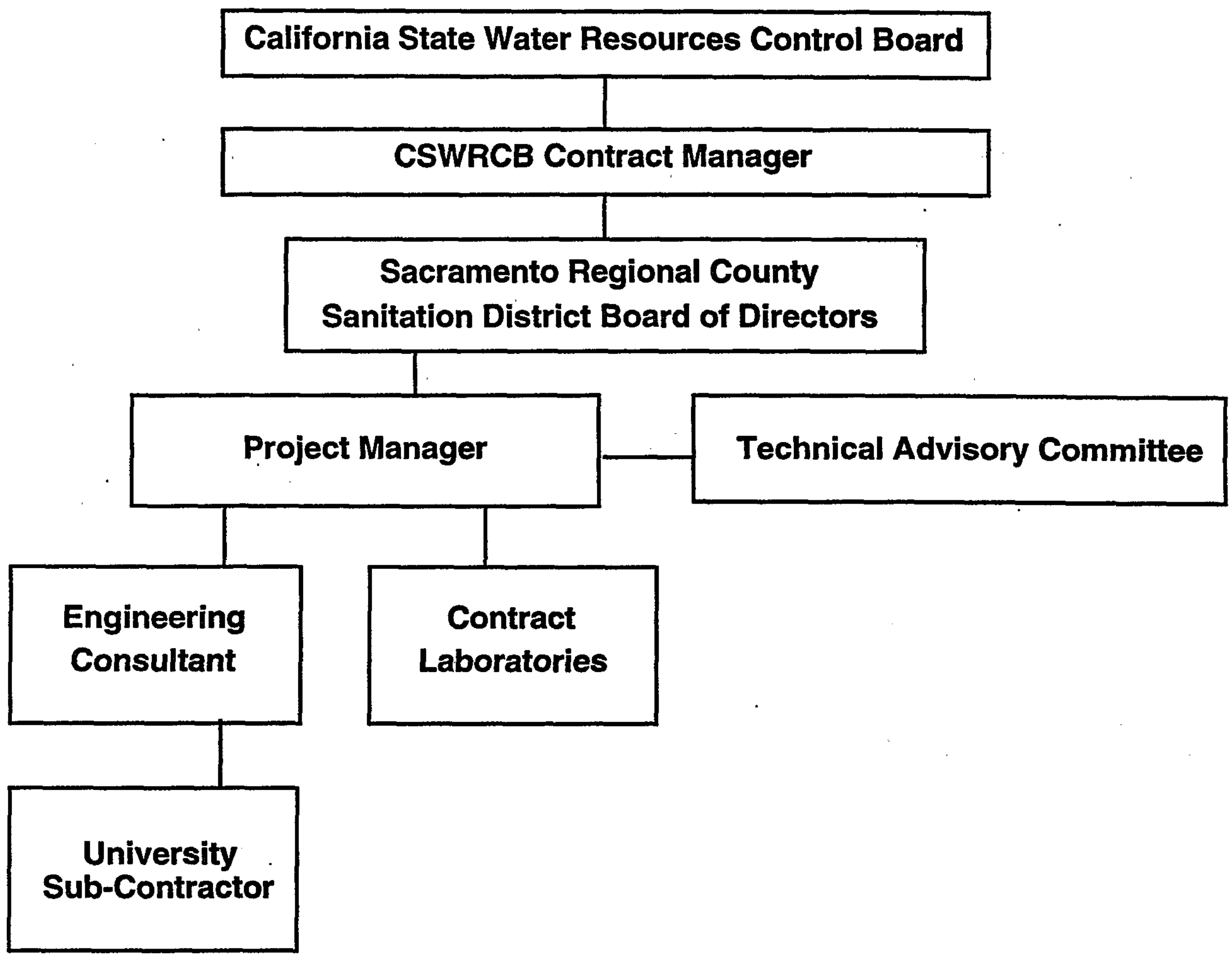

Fig 1. Management Structure

Problem Definition *(as in Water Quality Portion QAPP)*

Mercury in the Sacramento River Watershed

The CVRWQCB has determined that mercury causes an impairment of the aquatic habitat beneficial use in the Sacramento River between the Colusa Basin Drain and the Sacramento-San Joaquin Delta (SWRCB 1992a). The Department of Health Services has issued a consumer advisory limiting human intake of fish in the Sacramento-San Joaquin Delta (*ibid*).

Gold mining areas in the Feather River, Yuba River, and Bear River watersheds have been shown to be significant sources of mercury (CVRWQCB, 1987). However, point and nonpoint sources within these watersheds have not been identified or quantified in sufficient detail to facilitate the formulation of a strategy for controlling mercury emissions. For example, while mine tailings are known sources of mercury, the relative contribution to total loads in the Sacramento River from this source is not known (Montoya, et al., 1988) and has not been estimated using results of water column monitoring.

In 1986, the CVRWQCB conducted a survey of mercury contamination of sediment and fish throughout the Sacramento River watershed. Mercury was detected in elevated levels in sediment in the Yuba and Bear Rivers, Cache Creek, Putah Creek, and Stony Creek (CVRWQCB, 1987). Mercury levels in fish captured in water bodies in certain tributaries of the Sacramento River exceeded the National Academy of Sciences guideline to protect aquatic resources and their predators (0.50 ppm). These mercury bioaccumulation problems were observed in portions of the coast range where mercury is naturally occurring, in the Sierra Nevada Range where mercury was used (and is still used) to process gold, and in the Delta.

Regulation of Non-point Sources

Section 303(d) of the 1987 Clean Water Act (CWA) requires states to identify Water Quality Limited Segments (WQLS) where standards are not attainable after implementation of technology-based requirements (Best Available Technology/Best Control Technology). The Sacramento River from Shasta Dam to the Delta has been identified as a WQLS in the California Water Quality Assessment (SWRCB 1992a). This segment of the Sacramento River has also been given the highest ranking in terms of both resource value and degree of impairment by the State Board's Clean Water Strategy (SWRCB 1991).

Section 319(b) of the CWA requires that states implement nonpoint source (NPS) management programs and that these management programs involve public and private agencies and organizations which have expertise in control of nonpoint sources of pollution. Additionally, states are directed to develop NPS management plans on a watershed-by-watershed basis. Section 319(c) states that management plans also should be developed in cooperation with entities which are actively planning for the implementation of nonpoint source pollution controls.

Existing Management Plan: the TMDL Process

The CVRWQCB has begun a Total Maximum Daily Load (TMDL) process for heavy metal loadings (including mercury) from point and nonpoint sources in the Sacramento River watershed. This TMDL process includes the development of a mass emission strategy, identification of nonpoint sources, implementation of abatement and management programs, ambient monitoring, and monitoring of POTW and stormwater discharges.

Activities currently underway include development of a mass emission strategy by the CVRWQCB; implementation of mine drainage abatement projects by the CVRWQCB, the U.S.

EPA, the U.S. Forest Service, and mine owners; as well as development of a stormwater management program and monitoring of POTW and stormwater discharges by the City and County of Sacramento (SWRCB 1992c). The monitoring data used in the TMDL process come from special studies, self-monitoring programs imposed on dischargers, and ongoing monitoring programs operated by the CVRWQCB, the Department of Water Resources, the United States Geological Survey, and other local, state, and federal agencies.

Need for Additional Information

One of the limiting factors of many previous (and continuing) mercury studies has been that mercury levels in surface waters are usually below the analytical detection limits employed. Because of this, much of the information available regarding mercury concentrations in surface waters is of little use in identifying and characterizing sources.

To address the problem of high detection limits, and to further refine knowledge regarding upstream sources, the CVRWQCB initiated a two-year, watershed-wide mercury survey in 1992. This reconnaissance-level survey used methods capable of detecting mercury in water at concentrations in the 0.01 to 0.25 ng/L (parts per trillion) range (SWRCB, 1992b). Samples were drawn twice each year. Six sites located on the Sacramento River were sampled during both years. Twelve sites in northern Sacramento Valley reservoirs were sampled during the first year, and eleven sites in southern Sacramento Valley reservoirs were sampled during the second year. The results of this survey have provided important information regarding mercury sources on a region-wide basis. However, because the number of potential sources is much larger than the number of monitoring sites, further study will be needed before control strategies can be developed. For example, the watershed above one sampling location, located on the North Fork of the Yuba River at the confluence with New Bullards Bar reservoir, contains seven separate mines or mine drainage sites, each of which has the potential to be a significant source of mercury. Additionally, because of the limited number of samples being collected at each site, estimation of seasonal effects may not be feasible.

Project Description

The U.C. Davis portion of this project focuses on issues of mercury bioavailability and biological accumulation of mercury in the upstream regions of the Sacramento River Sierra Nevada watershed Specifically, this work will:

(1) Determine levels of mercury in aquatic biota at stream and river sites throughout the Sierra Nevada foothill gold region within the Sacramento River watershed.

(2) Using some of these organisms as bioindicators of localized mercury bioavailability, rank the major streams and tributaries as to their relative concentrations of bioavailable mercury. Included in this work will be determinations of relative mercury bioavailability in relation to foothill reservoirs; i.e. upstream vs downstream.

(3) Characterize the mercury levels in fish from the main reservoir of focus in the overall project, Englebright Reservoir.

(4) Investigate the relationship between aqueous mercury chemistry and corresponding bioaccummulation of mercury in aquatic biota.

Data Collection

A significant portion of the data to be utilized in this project has already been collected, between September 1993 and January 1995, funded by the Water Resources Center of the University of California. Data collection for the current project will involve sampling additional sites within the region in order to cover most major tributaries. It will also include more intensive sampling of specific areas. The data acquisition phase of the U.C. Davis portion of the current project is expected to run from March, 1995, through January, 1996, and will include four components:

(1) **Regional assessment of mercury in biota**: Multiple trophic levels of biota (as available) will be collected at stream and river sites not previously sampled in the earlier work. The combination of sites sampled from both studies should include most major tributaries distributed throughout the historic gold mining area of the northwestern Sierra Nevada Tissue samples will be analyzed for total mercury, with a subset analyzed for methyl mercury. Samples will be collected during summer and fall.

(2) **Localized assessment of mercury in biota**: More intensive biotic sampling (i.e. more closely spaced sampling sites) will be conducted along one or more rivers identified as being relatively elevated in bioavailable mercury levels. For this work, previously sampled sites will be re-sampled concurrently with the new collections.

(3) **Localized correlation between mercury in biota and corresponding aqueous mercury chemistry**: Multiple trophic levels of biota (as available) will be collected from upstream and immediately downstream of the reservoir around which water quality samples are collected (Englebright Reservoir). Tissue samples will be analyzed for total mercury, with a subset analyzed for methyl mercury. Samples will be collected several times throughout the year in coordination the water quality monitoring component of the study.

(4) **Localized assessment of mercury in Englebright Reservoir fish**: Fish will be collected from Englebright Reservoir and analyzed for total mercury in muscle tissue, for comparison with other regional fish and fish collected upstream and downstream of the reservoir.

This Quality Assurance Project Plan (QAPP) deals with the biota sampling portion of the study. A separate QAPP has been produced which addresses the water quality sampling portion of the study. A detailed description of the U.C. Davis project is provided below.

Project Objectives

The general objective of the overall project (including water quality and biota portions) is to develop an implementation plan for control of mercury from point and nonpoint sources within the Sacramento River watershed. The U.C. Davis biota mercury portion of the study will help meet this objective by:

(1) providing data from a regional assessment of mercury in aquatic biota and using this data to rank watersheds in terms of relative bioavailable mercury concentrations;

(2) using the results of more intensive sampling of biotic mercury in one or more elevated mercury streams to identify regions of highest bioavailable mercury levels;

(3) investigating the relationship of a foothill reservoir on downstream mercury bioavailability throughout a hydrologic year;

(4) characterizing fish mercury levels in a representative foothill reservoir;

(5) contributing to the identification and evaluation of mercury control options in the watershed of the Sacramento River.

Measurements

All components of the U.C. Davis portion of the project involve the collection and identification of aquatic organisms and the subsequent analysis of these organisms for total mercury at the U.C. Davis Environmental Mercury Laboratory. Splits from a subset of the samples will be analyzed for methyl mercury by Frontier Geosciences, the premier methyl mercury analytical facility in the world.

Water Quality Criterion

The US FDA health criterion for mercury in fish flesh is 1.0 mg/kg (wet wt). The Academy of Sciences guideline is 0.5 mg/kg, as is the guideline of the California Department of Health Services and guidelines from most other countries (TSMP 1990).

Assessment Tools

This QAPP will be reviewed by the Technical Advisory Committee, by the State Water Resources Control Board Quality Assurance Officer, and by the U.S. EPA Quality Assurance Manager.

Routine quality assurance data will be reviewed by the U.C. Davis team and the QA Manager.

QA Reports will be reviewed by the Project Manager.

Schedule

The timing of biotic sampling is based on three main considerations: (1) high stream flows and low water temperatures in winter and spring make in-stream sampling of benthic fauna difficult and hazardous, (2) many of the relevant organisms have annual life cycles and do not have an opportunity to accumulate significant mercury until later in the growing season, and (3) many of these organisms do not achieve significant biomass (re analytical constraints) until later in the season. For these reasons, aquatic biota samples will be collected primarily in the late summer and fall, similar to previous work in the region since 1993.

A portion of the sampling to be utilized in this project was conducted between September 1993 and January 1995, funded by the University of California Water Resources Center. Additional biota samples will be collected between March 1995 and January 1996. All biotic mercury data will be validated by March 1996. The implementation plan and final report for the project will be completed by October 1996.

Project and Quality Records Required

Quality records needed with biota total mercury (and methyl mercury) analyses include those associated with samples taken in the field (field duplicate results), and all relevant laboratory QC records (lab duplicates, standard reference materials, matrix spikes, method blanks.)

Data Quality Objectives for Measurement Data

Biotic Mercury Data Usage

For general bioavailable mercury distributional survey sites, data from this project will be used to:

- Rank sampled tributaries in terms of relative concentrations of bioavailable mercury.

For the representative reservoir and reservoir input/output sites, data from this project will be used to:

- Investigate the role of a foothill reservoir on aqueous mercury bioavailability, both within and downstream of the reservoir.
- Investigate the relationship between aqueous mercury chemistry and corresponding biotic mercury accumulation.

For the more intensive sampling in one or more higher mercury streams, data from this project will be used to:

- Identify localized regions with highest mercury bioavailability that may be suitable for future mitigation considerations.

Scope of the Project

<u>Domain (geographical, medium, time period)</u>

The project will encompass sampling sites located within the foothill gold region of the northwestern Sierra Nevada. Specifically, sites will be distributed within the watersheds of the Feather River, Yuba River, Bear River, and American River.

Biotic composite and/or tissue samples will be analyzed.

The field collection period starts in March 1995 and will continue through January 1996.

<u>Constraints on measurement project</u>

The measurement project is constrained by the resources available to provide for field crews to visit each sampling site, and by the resources available to provide for analysis of all samples collected. An additional constraint on the project is the ability to gain access to all proposed sites, some of which are very remote.

<u>Data needed</u>

Identification of collected aquatic biota to species for fish and to at least family for invertebrates. Total mercury concentration will be determined for each biotic sample. Splits of a subset of the samples will be analyzed for methyl mercury.

<u>Data uses</u>

The data from this project will be used for:

- Ranking concentrations of bioavailable mercury in tributaries within the Sierra Nevada portion of the Sacramento River watershed.
- Identifying localized regions of highest mercury bioavailability, potentially suitable for future mitigation considerations.
- Evaluating the impact of a reservoir on bioavailable mercury levels both within and downstream of the reservoir.
- Investigating the relationship between aqueous mercury chemistry and corresponding mercury accumulation in aquatic biota.

Decisions to be made

The data will be used to decide:

- Where significant sources of bioavailable mercury are located.
- What control measures may be appropriate.

Expected users of the data

The Central Valley Regional Water Quality Control Board will use results in their Total Maximum Daily Load process for heavy metals to develop a mercury control plan for the watershed.

Data Quality Objectives

The data quality objectives for this project are defined by the detection limits, precision, accuracy, and completeness associated with each type of measurement.

Detection Limits

Detection limits refer to the minimum concentration of a substance that can be measured and reported with 99% confidence that the analyte concentration is greater than zero.

Precision

Precision refers to the degree of agreement between individual measurements of a particular analyte from the same source. Precision is evaluated in terms of relative percent difference (RPD) between duplicate samples.

$$\text{RPD} = \frac{\text{difference between reported values}}{\text{average reported value}} \times 100\%$$

In cases where the values measured are very close to the detection limit of the method used, it is more appropriate to evaluate precision by comparing the absolute difference between duplicate measurements (DIFF in Table 1) to the detection limit.

Accuracy

Accuracy refers to the degree of agreement of a measured value with the true or expected value of the analyte. Accuracy for mercury concentrations will be measured, using standard reference materials (SRMs) when available, as the percent recovery (REC) of the certified value.

$$REC = \frac{\text{reported value}}{\text{certified value}} \times 100\%$$

Accuracy will also be measured as recovery (REC) of spiked samples.

$$REC = \frac{\text{spiked sample value - sample value}}{\text{spike value}} \times 100\%$$

Completeness

Completeness is defined as the percentage of samples that are completely analyzed and determined to be valid.

The data quality objectives for the project are listed in Table 1.

Table 1. Data Quality Objectives

Measurement	Detection Limit	Precision	Accuracy	Completeness
Total Mercury Concentration in Biota	0.02 mg/kg (ppm)	Lab Dup RPD ≤ 25% or DIFF ≤ 0.02 mg/kg Field Dup RPD ≤ 35% or DIFF ≤ 0.04 mg/kg	SRM REC = 100% ± 25% Lab Spike REC = 100% ± 25%	95%
Methyl Mercury Concentration in Biota	0.001 mg/kg	Lab Dup RPD ≤ 25% or DIFF ≤ 0.01 mg/kg Field Dup RPD ≤ 35% or DIFF ≤ 0.01 mg/kg	SRM REC = 100% ± 25% Lab Spike REC = 100% ± 25%	95%

Notes: RPD = relative percent difference; REC = recovery; DIFF = absolute difference between duplicate measurements, or between expected and actual measurement.

Representativeness

The biotic mercury data that will be generated by this project will indicate specifically the <u>bioavailable</u> <u>fraction</u> of mercury at each of the stream sites. It is understood that this fraction may represent a small portion of the total mercury load at each site. While this data will not permit the calculation of total mass loading of mercury at the biotic sampling sites, it will provide relative, time-integrated information on the portion of the mass mercury load that is available for uptake into the food chain. The water quality portion of the study (described in a separate plan) will address bulk, mass load mercury considerations for major trunk rivers. Regional biotic survey results will indicate relative mercury source regions throughout the upstream tributaries. As samples are taken from within the main stream channel, the sampled biota will have been exposed to aqueous mercury conditions typical of the main body of flowing water at each site.

Comparability

Trout muscle mercury data will be directly comparable to the large data base on fish muscle mercury concentrations accumulated by the California Toxic Substances Monitoring Program over the past 18 years (TSMP 1990). The use of invertebrate bioindicators of aqueous mercury bioavailability is a relatively new procedure that has been in development at U.C. Davis over the past 8 years. Extensive QA/QC has validated this technique and a large comparative data base now exists (Slotton 1991, Slotton et al. 1995 a & b). The invertebrate mercury data can also be compared to the regional fish data (TSMP 1990).

Documentation and Records

Data to include in a data report package

For each sample analyzed at U.C. Davis for total mercury or submitted to Frontier Geosciences for methyl mercury, the laboratory shall provide to the Engineering Consultant the sample ID, the measured value of the constituent in question, the date of analysis, and the date of sample receipt (or sample collection for U.C. Davis). Additionally, the laboratory shall provide results from all laboratory QC procedures (blanks, duplicates, spikes, reference materials) associated with each sample batch, and the sample IDs associated with each batch.

Lab reporting turnaround time

Lab turnaround time for full lab reports for mercury analyses will be 6 weeks from sample receipt.

DATA ACQUISITION

Experimental Design

Type of Samples

Invertebrate samples for mercury analysis will consist of composites of one or more (typically 2-50) individuals of same type and similar size, dried and homogenized to an even powder. Fish mercury will be determined in fresh muscle tissue (fillet) taken from the dorso-lateral (shoulder) region, using protocols similar to those used by the California Department of Fish and Game Toxic Substances Monitoring Program (TSMP 1990).

Sampling Network Design, Rationale for the Design, and Guidelines for Selecting Sampling Points

Biota sampling sites were selected to rank tributaries in terms of relative bioavailable mercury concentrations, to define the region of highest mercury bioavailability in one or more streams, to estimate the impact of reservoirs on downstream water quality, and to support the water quality sampling portion of the overall project.

The three sites around Englebright Reservoir which are used to compare with water collections will be identical to the water collection sites chosen for this portion of the water quality sampling.

The large number of additional biotic sampling sites, including those previously sampled in the University of California Water Resources Center Project (Slotton et al. 1995) and those newly sampled in this project, are distributed throughout the gold region of the Sierra Nevada portion of the Sacramento River watershed. An effort has been made to sample all major tributaries. Specific sampling sites were chosen so as to accomplish this basic goal while being generally accessible to the field collection team. Specific sampling sites are listed in Table 2 and displayed in Figure 2. Additional sites will be sampled on one or more streams found to be relatively higher in bioavailable mercury concentration.

Table 2. U.C. Davis Sacramento River Watershed Sierra Nevada Gold Region Biota Mercury Sites (bold = sites to be sampled in the current project)

FEATHER RIVER DRAINAGE

1. **Lower Feather River below Lake Oroville.**
2. **West Branch Feather River above Lake Oroville.**
3. **North Fork Feather River above Lake Oroville.**
4. North Fork Feather River at Belden.
5. Yellow Creek (tributary to N Fk Feather R), 2 miles above confluence.
6. Caribou Branch of North Fork Feather River, 4 miles above confluence.
7. East Branch of North Fork Feather River, 10 miles above confluence with Caribou Branch.
8. Indian Creek, tributary to E Branch N Fk Feather River, 7 miles above confluence.
9. Spanish Creek, tributary to E Branch N Fk Feather River, 2 miles above confluence.
10. **Middle Fork Feather River, 15 miles upstream of Lake Oroville.**
11. Middle Fork Feather River, 1 mile below Nelson Creek.
12. Nelson Creek, tributary to Middle Fork Feather River, 1 mile above confluence.
13. Upper Middle Fork Feather River, 3 miles upstream of Clio.
14. **Fall River, tributary to lower Middle Fork Feather River, 3 miles above confluence.**
15. **South Fork Feather River above Lake Oroville.**

YUBA RIVER DRAINAGE

16. Lower Yuba River below Englebright Reservoir, at University of California field station. (****Multiple samplings****)
17. **Combined North and Middle Forks Yuba River, 1/2 mile below Colgate Power House. (**Multiple samplings**)**
18. North Fork Yuba River constrained (low) flow beneath New Bullard's Bar Reservoir.
19. North Fork Yuba River, 2 miles downstream of westmost Highway 49 crossing.
20. Canyon Creek, tributary to N Fk Yuba, just above confluence.
21. Downey Creek, tributary to N Fk Yuba, at Downieville.

Table 2. (continued)

22. Middle Fork Yuba River, just upstream of Oregon Creek and Highway 49 crossing.
23. Middle Fork Yuba River, 1 mile upstream of Tyler Foote crossing and Kanaka Ck.
24. Middle Fork Yuba River, 1 mile upstream of Plumbago Road.
25. **South Fork Yuba River at Bridgeport. (**Multiple samplings**)**
26. **South Fork Yuba River just upstream of Highway 49 crossing.**
27. South Fork Yuba River 1 mile downstream of Washington.
28. Deer Creek below Lake Wildwood, at Mooney Flat Road.
29. Deer Creek at Bittney Spring Road.

BEAR RIVER DRAINAGE

30. Bear River below Camp Far West Reservoir.
31. Bear River between Camp Far West Reservoir and Wolf Creek confluence.
32. Wolf Creek, tributary to Bear River, 2 miles above confluence.
33. Bear River below Rollins Reservoir.

AMERICAN RIVER DRAINAGE

34. Lower American River at Howe Avenue.
35. Lower American River 1 mile below Lake Natoma.
36. **Combined North and Middle Forks American River above Folsom Lake.**
37. North Fork American River in vicinity of Humbug Bar.
38. Middle Fork American River below Oxbow Reservoir.
39. North Fork of the Middle Fork American River, 1 mile above confluence.
40. Rubicon River, tributary to Middle Fork American River, just above confluence.
41. Middle Fork American River at "End of the World".
42. Duncan Creek, tributary to Middle Fork American River, 3 miles above confluence.
43. South Fork American River above Folsom Lake.
44. South Fork American River below Slab Creek Reservoir.
45. South Fork American River 1 mile upstream of Pacific.

(Plus additional sites along one or more streams relatively elevated in mercury, such as the South Fork Yuba River, and/or the Middle Fork Yuba River, and/or the Bear River).

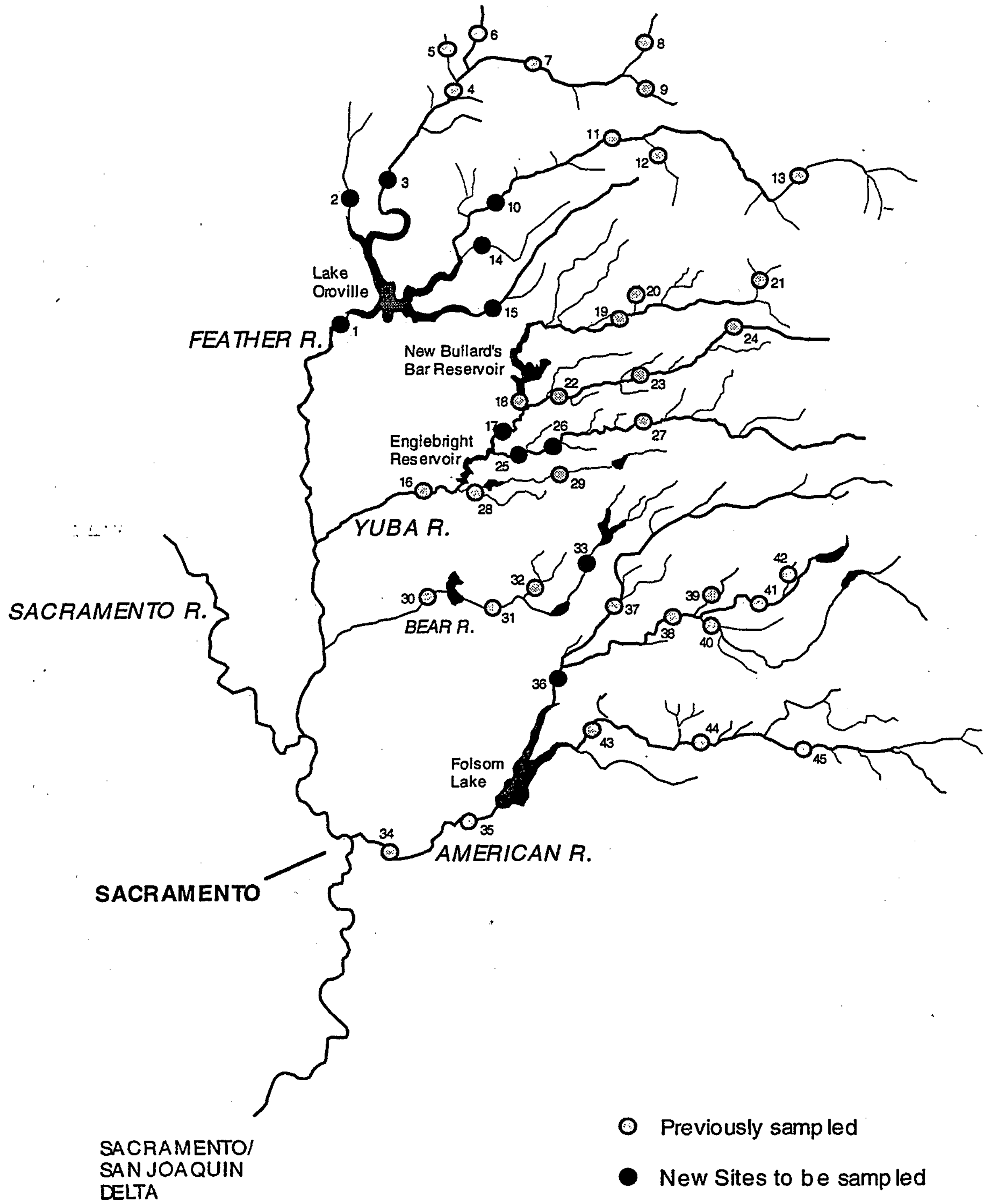

Figure 2. U.C. Davis Sacramento River Watershed Sierra Nevada Biotic Sampling Sites
(plus more intensive sampling from the Middle Fork Yuba River, and/or the South Fork Yuba River, and/or the Bear River)

Coordination with water quality sampling sites

Many locations within the Yuba River watershed exhibit high levels of bioaccumulation (Slotton, 1995). As part of this project, multiple trophic levels of biota will be sampled from numerous sites within the Yuba River watershed upstream of Englebright Reservoir to determine levels of bioaccumulation. Biota samples will also be collected from the input/output reservoir water quality monitoring sites, in coordination with water sampling. Water quality data collected from these sites will be used to explore relationships between water quality and bioaccumulation, and to investigate the impact of the reservoir on these relationships.

Sampling Schedule/Frequency

For the reservoir inflow/outflow sampling sites which will be sampled in coordination with the water quality sampling, aquatic biota will be collected on several different dates from the three sites. Biota sampling will not be concurrent with water sampling, as biotic accumulation of mercury occurs over weeks and months of continuous uptake. These samples will be collected on an off-set schedule, approximately midway between water samplings. The preceding water sampling will be used to approximate aqueous concentrations experienced by the organisms over the previous month or two.

For the basic distributional survey work, sites will generally be sampled only once for basic characterization. The sampled biota will have integrated mercury availability over their lifespans. The exact schedule of sampling during the summer, fall and early winter months will depend on weather conditions and other project schedules.

Sample Matrices

All samples shall be of aquatic biota. Invertebrate samples will be analyzed on a dry weight basis, utilizing a homogeneous powder of each composite sample, as in extensive earlier work by this research laboratory. Composites shall consist of 1-50 individual organisms of same type and similar size from each location. Fish mercury will be analyzed on a wet weight (fresh) basis on muscle tissue from individual fish, in accordance with the protocols of the California Department of Fish and Game and existing Health Criteria.

Measurement Parameters of Interest

Biota identification, total mercury concentrations. Additionally, methyl mercury will be analyzed on splits of a subset of the biota samples.

Guidelines for Selecting Sampling Equipment

Aquatic invertebrate samples will be collected from stream riffle habitat, using two field personnel operating an invertebrate kick screen. Rainbow trout will be taken from upstream sites by angling, which has been found to be the most effective collection technique. Fish will be collected from Englebright Reservoir primarily with the use of experimental gill nets of variable mesh size. Specific sampling procedures are described below.

Invertebrate Total Mercury and Methyl Mercury

The following sections describe the standard operating procedure (SOP) for collection of invertebrate samples for total mercury and methyl mercury analysis.

Materials Needed

Invertebrate samples will be collected into 30 ml glass jars with teflon-lined caps. Invertebrate kick screens will be constructed with heavy duty stainless steel screening, fastened securely to wooden dowels at both sides with brass wire. A 1.5 mm mesh size will be used, trapping invertebrates larger than this in cross section. Teflon-coated forceps will be used to pick organisms from the screen. An acid-cleaned laboratory pan will be used to clean the collected organisms in fresh water.

Decontamination

New jars are cleaned by rinsing in site stream water at the time of collection and finally by rinsing in 1% HCl before adding the cleaned organisms, following rinsing of organisms in column-distilled water.

Sample Collection

Stream invertebrates will be taken from riffle habitat at each of the sites, i.e. from rapids or cobble bottomed stretches with maximal flow, where aquatic insects tend to be most concentrated among the rock interstices. Felt-soled boots will be used to permit effective movement in this habitat. Neoprene waders will be used when water temperatures are below ~10 °C. Stream invertebrates will be collected primarily with the use of a kick screen (described above). At each site, one researcher will spread and position the screen perpendicular to the flow, bracing the side dowels against the bottom, while the other researcher overturns boulders and cobble directly upstream of the screen. These rocks will be hand scrubbed into the flow, dislodging any clinging biota. Following the removal of the larger rocks to the side of the stretch, the underlying cobble/pebble/gravel substrate will be disrupted by shuffling the boots repeatedly. Invertebrates are washed into the screen by the current. The screen is then lifted out of the current and taken to the shore, where teflon coated forceps are used to pick macro-invertebrates from the screen into jars with teflon-lined caps. This process is repeated until a sufficient sample size of each taxon of interest is accumulated to permit future analysis for mercury.

Preservation

Samples in jars will be maintained live on ice, to be cleaned in fresh water within 24 hours of collection. This cleaning will be accomplished by suspending sample organisms in fresh water and, as necessary, shaking individuals in the water with teflon-coated forceps to remove any significant clinging surficial material. Cleaned organisms will be stored in acid-cleaned jars with teflon-lined caps, which will be frozen and then dried at 50-60 °C.

Holding Times

Samples will generally be analyzed within 60 days of sample collection, though the cleaned and frozen or dried samples are stable indefinitely.

Performance Requirements

This sample collection technique requires that the cleaned samples consist solely of the collected organisms, minus any significant surficial sediment.

What to do if a Failure Occurs

If the performance requirements listed above cannot be met, the sample will not be analyzed.

Responsibility for Corrective Action

It is the shared responsibility of all members of the field crew to determine if the performance requirements have been met and to collect additional samples if required.

Fish Total Mercury

The following sections describe the standard operation procedure (SOP) for collection of fish samples for total mercury analysis.

Materials Needed

Angling gear, Pesola scales for weighing individual fish, rulers for determining fork length, scalpels, fresh stainless steel scalpel blades, laboratory tissue paper, pre-weighed, pre-cleaned laboratory digestion tubes with teflon-lined caps for muscle samples. For fish collections in Englebright reservoir, experimental gill nets of various mesh sizes will be utilized to obtain fish.

Decontamination

Digest tubes and caps will be acid washed with concentrated nitric and sulfuric acid, scrubbed manually, and rinsed multiple times in de-ionized water which has been passed through multiple ion-exchange resin columns. Fresh, stainless steel scalpel blades are utilized in the field to remove muscle samples.

Sample Collection

Several fish collection techniques were investigated initially, including gill netting, electroshocking, and angling. We determined that angling was the most effective method for taking a cross section of trout sizes from clear, fast moving Sierra foothill rivers and streams. To guard against potentially taking seasonal migrant fish from downstream reservoirs, fish sampling is largely confined to the months of August through December. Stocked individuals are rarely taken and are easily differentiated from native fish by their characteristic fused and bent fin rays. We will sample exclusively native fish for mercury content, with the emphasis on rainbow trout. The attempt will be made to collect trout across a range of sizes and ages at each site, permitting the construction of site-specific fish size vs mercury regressions. These relationships will be used to normalize trout mercury content at each site to a standard, inter-comparable size of trout. We use a standard size of 250 g for normalization. This size is typical of 2-3 year old, 9-12 inch long trout which represent the majority of "keeper" fish taken by the angling public. Fish will be weighed and measured in the field.

Fish mercury will analyzed in muscle tissue on a fresh (wet) weight basis, in accordance with standard practices which focus on the potential health risks of consuming mercury in fillet meat (TSMP 1990). Muscle samples will be taken from fresh fish at streamside. Fish muscle will be sampled from the dorso-lateral (shoulder) region utilized by the California Department of Fish and Game. For each individual fish, the skin over the region will be pulled back before the sample is taken with a stainless steel scalpel. Samples of approximately 2.0 g will be rolled lightly over a laboratory tissue paper to remove extraneous surface moisture and then carefully placed into pre-weighed, acid-washed digestion tubes with teflon-lined caps. The precise weight of each muscle sample will be later determined by re-weighing the digestion tubes with samples, together with empty "blank" tubes, on a balance accurate to 0.001 g. This direct sub-sampling technique reflects fresh weight muscle (fillet) mercury concentrations, without introducing potential sources of error associated with homogenization techniques. We have found mercury concentration to be extremely uniform throughout the dorso-lateral region of muscle (Slotton 1991). Thus, direct sub-sampling accurately reflects overall muscle mercury concentration.

Preservation

Once collected and sealed into digestion tubes, muscle samples will be stable indefinitely, as determined in previous work. Digestion tubes containing samples will be transported to the U.C. Davis laboratory, where they will be re-weighed (together with blanks pre-weighed with sample tubes) to determine the precise weight of sample in each tube. Tubes will then be maintained frozen until sample digestion and mercury analysis is to be performed.

Holding Times

Samples will generally be analyzed within 60 days of collection, though, once sample weights are determined and tubes are frozen, samples are stable indefinitely.

Performance Requirements

This sample collection technique requires that the fish muscle samples are placed into the digestion tubes without extraneous clinging moisture and without any contamination from surficial skin or other material.

What to do if a Failure Occurs

If the performance requirements listed above cannot be met, the sample will not be analyzed.

Responsibility for Corrective Action

It is the shared responsibility of all members of the field crew to determine if the performance requirements have been met and to collect additional samples if required.

Sample Handling and Custody Requirements

Field Log

Field crews shall keep a field log throughout each sampling run. For each sampling event, the following items shall be recorded:

- Location and description of sample collection site.
- Date of sample collection.
- ID number on mercury digestion tubes used.
- Organisms collected.
- Water temperature.
- A subjective evaluation of flow conditions at time of sample collection.
- Any unusual occurrences associated with the sampling event.

Lab custody log

Laboratories shall maintain lab custody logs sufficient to track each sample submitted and to analyze or preserve each sample within the holding times specified.

Examples of sample documentation forms

An example of chain of custody (COC) forms is shown in Figure 4.

Chain-of-Custody (COC)

To: Frontier Geosciences Inc.
414 Pontius Avenue North
Seattle, WA 98109
(206) 622-6960

From:____________________

bottle #	sample location	depth	date/time	collected by	preservation	analyses needed

Relinquished by: NAME SIGNATURE DATE TIME

Recieved By: NAME SIGNATURE DATE TIME

Comments:

QA Level Desired: ( ) Normal Research ( ) EPA CLP Style (high level, 30% additional cost)

Figure 3. Example COC Form

Labeling Procedures

Total Mercury Samples

Digestion tubes used for fish muscle samples are pre-labelled with etched identifications. Glass jars with teflon-lined caps for invertebrate samples are labelled on both caps and jars following collection.

Methyl Mercury Samples

Split samples of homogenized, dry powders of selected invertebrate composites for methyl mercury analysis will be sent to Frontier Geosciences in 30 ml glass jars with teflon-lined caps. These jars will be labelled both on the caps and the jars. The following information will be included:

- Site
- Date collected
- Sample type

Procedures for transferring and maintaining custody

Chain of custody will not be a consideration for the total mercury biota collections and analyses which form the majority of this portion of the overall project. This is because the same researchers collecting the samples in the field will be preparing and analyzing the samples in the university laboratories, and the same researchers will be handling QA/QC and reduction and interpretation of the data. For methyl mercury splits, field crews shall have custody of samples during field sampling. Chain of custody forms shall accompany all samples during shipment to the contract laboratory.

Analytical Methods Requirements

Method - Total Mercury Analysis

Total mercury is determined at U.C. Davis by a modified Cold Vapor Atomic Absorption (CVAA) technique (Slotton et al. 1995 a). Digestion is performed in teflon-capped pyrex test tubes in a two stage process. Environmental samples are broken down in a 2:1 mixture of concentrated sulfuric acid to concentrated nitric acid. This first stage utilizes a temperature of 90-100 °C and pressure (sealed tubes) for 1.5 hrs, resulting in clear solutions. In the second stage, also 1.5 hrs, potassium permanganate is added for additional oxidation and digest stabilization. This portion of the digest procedure is performed at 80-95 °C with the tubes refluxing, uncapped. The resulting digests can be diluted or not, depending on the mercury concentrations and required level of detection, and are stable indefinitely, both before and following detection.

Detection utilizes typical cold vapor atomic absorption techniques with a mercury lamp of 253.7 nm wavelength. The method differs from standard flow-through systems which reduce the entire digest in a one-time detection. A long path length, minimum volume gas cuvette and holder have been manufactured for positioning in the beam path and a specialized injection port allows direct introduction of reduced mercury in vapor. Reduction of digest mercury is performed inside a 12 cc calibrated syringe on a 2.0 cc aliquot of digest together with 2.0 cc of stannous chloride/hydroxylamine sulfate/sodium chloride reductant. A 6.00 cc airspace is utilized for partitioning of the volatile reduced mercury within the syringe and, after partitioning is complete, this airspace is injected directly into the low volume cuvette mounted in the beam path for detection. The amount of digest and, thus, proportion of sample detected is accurately determined through difference, with the digest tubes weighed to ± 0.001 g both before and immediately after removal of the analytical aliquot. Weight of total digest is initially determined by weighing the empty tube and then the full tube of digest. Level of detection is approximately 0.01 mg kg^{-1} (ppm).

Method - Methyl Mercury Analysis

Methyl mercury is determined at Frontier Geosciences using aqueous phase ethylation to generate a volatile methyl ethylmercury derivative of methyl mercury in the sample. This compound is then chromatographed by cryogenic gas chromatography and pyrolytically broken down to elemental mercury. Samples are pre-reduced with $NH_2OH{\bullet}HCl$ and then further reduced with $SnCl_2$ and purged onto gold traps with purified nitrogen.

The gold traps are then heated and the mercury desorbed into inert carrier gas (ultra-pure argon or helium) for detection by cold-vapor atomic fluorescence spectroscopy (CVAFS) (Bloom and Fitzgerald 1988). The excitation source is a 4-W low pressure mercury vapor lamp, emitting predominantly at 254 nm, and the detector is a UV-visible general purpose photomultiplier shielded from stray light with a 253.7 nm interference filter. Atomic fluorescence is monitored at 90° to the direction of the excitation beam, through a 10-mm square fluorescence cell.

Performance Requirements

Table 2 summarizes the quality control procedures and the related acceptance criteria employed in the project.

All samples shall be analyzed using standard operating procedures. Any deviation from these procedures shall be considered a failure to meet performance requirements. Additionally, failure to meet the data acceptance criteria listed in Table 2 for laboratory generated QC samples shall be considered a failure to meet performance requirements.

What to do if a Failure Occurs

If a failure occurs, the analytical equipment shall be checked, repaired, and re-calibrated if necessary. Affected samples shall be re-analyzed.

Responsibility for Corrective Action

It is the responsibility of the laboratory to perform these corrective actions.

Quality Control Requirements

The quality control procedures used in the laboratory and in the field, the frequency and acceptance criteria, and corrective actions to be taken are presented below in Table 3.

Table 3. Quality control procedures, frequency, and acceptance criteria.

Measurement	QC Procedure	Frequency	Acceptance Criteria	Corrective Action
Total Mercury DL = 0.02 mg/kg	Lab duplicate	1 per 15 samples	RPD ≤ 25% or DIFF ≤ 1 DL	recalibrate and/or reanalyze both samples
	Lab Spike	1 per 15 samples	REC = 100% ± 25%	recalibrate and/or reanalyze
	Aqueous Mercury Standards	6 per analytical batch	Standard Curve r^2 corellation coefficient > 0.95	reanalyze all samples in batch
	Method Blank	1 per analytical batch	n/a (results are blank-corrected)	reanalyze all samples in batch
	Standard Reference Material	1 per 10 samples	REC = 100% ± 25%	recalibrate and/or reanalyze
	Field Duplicate	1 per sampling run	RPD ≤ 35%	reanalyze both samples and increase frequency of field duplicates
Methyl Mercury DL = 0.001 mg/kg	Lab duplicate	1 per 20 samples	RPD ≤ 25% or DIFF ≤ 1 DL	recalibrate and/or reanalyze both samples
	Lab Spike	1 per 20 samples	REC = 100% ± 25%	recalibrate and/or reanalyze
	Method Blank	3 per analytical batch	n/a (results are blank-corrected)	reanalyze all samples in batch
	Standard Reference Material	1 per 20 samples	REC = 100% ± 25%	recalibrate and/or reanalyze
	Field Blank	1 per sampling run	Blank < 0.15 ng/L	Examine field log. Re-train sampling crew. Note "hit" on all results from that sampling run.
	Field Duplicate	1 per sampling run	RPD ≤ 35%	reanalyze both samples and increase frequency of field duplicates

Notes: RPD = relative percent difference; REC = recovery; DIFF = absolute difference between duplicate measurements, or between expected and actual measurement.

Instrument/Equipment Testing, Inspection, and Maintenance Requirements

Field Equipment

Field equipment is maintained in condition suitable for collection of biological samples.

Lab Equipment

Frontier Geosciences

Frontier Geosciences' lab equipment is tested, inspected, and maintained as described in their quality assurance manual (see Appendix A of QAPP for Water Quality portion of the project).

U.C. Davis

At U.C. Davis, the laboratory water bath is checked for correct temperature and stability prior to each digestion. The Atomic Absorption Spectrophotometer is run through a rigorous checkout procedure prior to each analytical run. Laboratory balances are checked against callibration weights daily.

Instrument Calibration and Frequency

Field Equipment

(Not applicable).

Lab Equipment

Frontier Geosciences

Frontier Geosciences' lab equipment is calibrated as described in their quality assurance manual (see Appendix A of QAPP for Water Quality portion of the project).

U.C. Davis

(As above) the laboratory water bath is checked for correct temperature and stability prior to each digestion. The Atomic Absorption Spectrophotometer is run through a rigorous checkout procedure prior to each analytical run. Laboratory balances are checked against callibration weights daily.

Data Acquisition Requirements (Non-direct Measurements)

(Not applicable for this portion of the project).

Data Management

Copies of chain of custody forms, preliminary and final lab reports, and electronic media reports will be sent to the Engineering Consultant. Each type of report will be stored in a separate file folder and will be ordered chronologically. Field logs will remain with U.C. Davis personnel. Original chain of custody forms, and copies of the preliminary and final data reports shall be kept by the Contract Laboratories.

Data will be transferred to a personal computer in the office of the University sub-contractor. Checks will be performed following every data entry or data transfer procedure to determine if any data transcription errors occurred.

ASSESSMENT

Assessment and Response Actions

Assessments of compliance with quality control procedures will be undertaken on a routine basis during the data collection phase of the project.

Performance assessments of sampling procedures will be performed by field sampling crews. Corrective actions shall be carried out by field sampling crews and shall be reported to the Engineering Consultant.

Assessment of laboratory QC results and implementation of corrective actions will be the responsibility of the QA officer at each laboratory and shall be reported to the Engineering Consultant.

Assessment of field QC results and implementation of corrective actions shall be the responsibility of the U.C. Davis Sub-contractor.

Routine procedures to assess precision and accuracy, criteria for success, and response actions, are listed in Table 2.

QA Reports to Management

Following review of results from each sampling run, the U.C. Davis Sub-contractor shall provide to the Quality Assurance Manager a Quality Assurance Report which summarizes the status of the project, results of performance evaluations and system audits, results of periodic data quality assessments, and significant QA problems associated with the sampling run and recommended solutions. On a quarterly basis, these reports will be summarized and sent to the Project Manager and the State Water Resources Control Board Contract Manager as part of the normal quarterly status reports.

DATA REDUCTION, VALIDATION, REPORTING AND USABILITY

Reduction

Total mercury concentrations will be calculated with the use of mercury vs absorbance curves generated from an extensive set of mercury standards (including blanks) which are carried through all phases of the digistion and detection procedures for each analytical batch.

Methyl mercury concentrations shall be calculated as set forth in the QA Manual for Frontier Geosciences (Appendix A of the QAPP for the Water Quality portion of the project). The values reported shall be corrected for method blank or reagent blank concentrations.

Validation

The Data quality objectives listed in Table 2, in addition to standard data validation procedures set forth in each laboratory's QA Manual, shall be used to accept, reject, or qualify the data generated by each lab. Each laboratory QA Officer shall be responsible for validating data generated from each lab. The Engineering Consultant shall be responsible for validating all data based on evaluation of field and lab QC samples.

Reporting

The Engineering Consultant shall prepare and submit all water quality-related data generated by the overall project to the State Board for input into the SWQIS/STORET system. Data shall be submitted to the State Board Information Services Office on computer diskette or on forms provided by the State Board. The Engineering Consultant shall be responsible for verification of data quality of all such media.

Usability

Data that meet the data quality objectives of Table 2 shall be considered usable for purposes of this study. It shall be the responsibility of the U.C. Davis Sub-contractor to resolve any issues related to data quality and to provide an estimate of uncertainty associated with unverified data.

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APPENDIX E:

RESPONSIVENESS SUMMARIES

Responsiveness Summary For Sacramento River Mercury Control Planning Project: Public Meeting No. 1

A Public and Technical Advisory Committee (TAC) meeting was held on October 20, 1994. The purpose of the meeting was to discuss the Sacramento River Mercury Control Planning Project study plan. Attendees included members of the TAC, study team members, regulatory agency representatives, and members of the interested public (See Attachment A). On January 30, 1995, a revised study plan was distributed to the TAC with a request for comments. Comments were received on both the October and January versions of the study plan, resulting in significant modifications to the study plan. A summary of the significant comments and the responses to those comments is found below.

It was suggested that electrical conductivity (EC) be added to the list of field measurements. pH, dissolved oxygen (DO), temperature, and EC are measured simultaneously by the Datasonde currently used by Sacramento's Ambient Monitoring Program (AMP). This equipment is readily available for use in the Mercury Study. In addition, chloride concentrations (which are often correlated with EC measurements), significantly affect inorganic mercury speciation. This modification would provide useful information and would have no budgetary impact to the project. Therefore, both EC and DO measurements have been added to the list of field measurements.

A suggestion was made to include measurements of water hardness and redox potential. Because hardness is highly correlated with electroconductivity, it was decided that direct measurement of hardness measurements would not provide sufficient additional information to warrant the additional analytical expense. The redox potential of natural waters is controlled primarily by dissolved oxygen concentrations and organic content. In the well-aerated Sierran streams being sampled, the redox potential is not expected to vary significantly, and it was decided that direct analysis of redox potential would not be likely to provide information sufficient to warrant the additional analytical expense.

It was suggested that a sampling site pair be added where the Bear River joins the Feather River. While this would help to gain an understanding of loading from the Bear River/Dry Creek Watershed, it would result in a substantial additional cost to the project. This modification was felt to be outside the scope of the project and too costly (~$27,000), so these sampling sites were not added.

It was suggested that sediments in streams and in one reservoir be studied. The rationale for the suggestion was that conditions measured using water quality samples will probably only apply to a limited time frame and may not accurately represent long term conditions. The lack of sediment data will prevent the study from assessing historical reservoir removal rates or evaluating the significance of bedload transport in Sierran streams. While useful information would be gained by modification of the study to include additional sediment data collection, the budgetary impact of a modest sediment sampling effort (estimated to be somewhere between $21,000 and $63,000) was too great to add sediment evaluations beyond total suspended solids concentrations to the project. Additionally, questions exist regarding the ability to interpret the sediment data that would be collected.

It was suggested that samples be analyzed for total and dissolved monomethyl (not dimethyl) mercury. The original study plan was revised to include (incorrectly) dimethyl mercury analysis. Dimethyl mercury is volatile, non-polar, and very poorly soluble in water. Monomethyl is the toxic species of most concern. The additional analysis for this parameter is relevant to the study objectives and the cost would be an additional $2,000. The study plan has been modified to include monomethyl mercury analysis at the reservoir sampling sites.

It was also suggested that *all* samples be analyzed for total and dissolved monomethyl mercury. It was decided that the cost (~$15,000) to extend these analyses to all of the river sites was too expensive to include in the study.

It was suggested to extend the study from 9 months to 12 months. Mercury methylation will probably be highest in summer and fall. Sediment transport will be probably highest in winter and spring. Therefore, it was suggested all seasons be studied to gain a representative view. The budgetary impact is estimated to be $35,000 (approximately 33% of water quality sampling effort). The sampling plan has been modified to collect samples during three key seasons or hydrographic regimes: winter storms, spring runoff, and mid-to-late summer, which span the annual hydrographic cycle.

It was suggested that Englebright Reservoir be sampled instead of New Bullards Bar Reservoir. It is believed that the South and Middle Forks of the Yuba may be the rivers with the highest mercury concentrations in the project area, so this would be very relevant sampling. It's likely that each fork will be found to be a "hot spot". Downstream from Englebright Reservoir is a large river that is directly pertinent to downstream water supply. It also has a rich biota and good riffle habitat. The study plan has been modified to substitute the Englebright Reservoir for the New Bullards Bar Reservoir.

It was suggested that 50 biota samples be analyzed for methyl mercury (at Frontier Geosciences). Speciation of the tissue mercury will be important in interpreting the larger set of total mercury data. It is needed to link the water chemistry phase of the overall project with the biota and bioavailability aspects. The proportion of methyl mercury to total mercury in selected samples will indicate (1) the relative importance of in-stream methylation and (2) the relative characteristics of the various species as indicators of total (vs. methyl) mercury presence and availability. Additional analytical costs ($14,643) necessary for this are partially offset because costs associated with the UC Davis portion of the study are lower than initially estimated. Therefore, the budgetary impact of this modification would only be ~$1,500. This has been added to the study plan. A separate Quality Assurance Project Plan addresses the biota sampling portion of the study.

Table E-1. October 20, 1994 First Public Project Meeting: Meeting Attendees.

name	affiliation
Technical Advisory Committee	
Bill Croyle	CVRWQCB
Dick Zembec	US Forest Service
Jerry Miller	Desert Research Institute
Rick Humphreys	State Water Resources Control Board
Ron Churchill	Division of Mines and Geology
Sean Hogan	Environmental Engineer
Chris Stathos	Mother Lode Skin Diving Shops
Peter Richerson	UC Davis
Dave Sbaffi	Cal Sierra Development Company
Michael Pickering	Brush Creek Mining and Development Co.
Steve Swarzbach	U.S. Fish and Wildlife Service
David Crane	California Dept. of Fish and Game
Don Porcella	Electric Power Research Institute
Other Interested Individuals	
Carolyn d'Almeida	USEPA - Region 9
Cecilia Horner	USFS
Clarence Calahan	USEPA - Region 9
Julie Tupper	USFS
Steve Boggs	Cal. Dept. of Fish and Game
Maggie Manderbach	U.S. Forest Service
Charles M. Bertolette	
Margie Lopez	Eldorado Irrigation District
Jerry Boles	California Department of Water Resources
Donn Wilson	Yuba County Water Agency
Paul Pugner	US Army Corps of Engineers
Terry V. Mayfield	Nevada Irrigation District
Harlan Hamburger	US Forest Service
Dean Swickerd	US Bureau of Land Management
Steve Anderson	US Geological Survey
Mike Heath	US Forest Service
Steve Boggs	Cal. Dept. of Fish and Game

RESPONSIVENESS SUMMARY FOR SACRAMENTO RIVER MERCURY CONTROL PLANNING PROJECT: PUBLIC MEETING NO. 2

A Public and Technical Advisory Committee (TAC) meeting was held on January 28, 1997. The purpose of the meeting was to present the results of the Sacramento River Mercury Control Planning Project. Attendees included members of the TAC, study team members, regulatory agency representatives, and members of the interested public (Table E-2). Comments were also received on the Draft Final Project Report, distributed to the TAC in December, 1996. Questions and comments (and responses) received during the meeting are documented in the meeting transcripts below. A summary of the significant comments and the responses to those comments is provided in Table E-3. A summary of significant outgrowth issues raised during the January 28 meeting is presented in Table E-4.

Table E-2. January 28, 1997 Final Public Project Meeting: Meeting Attendees.

name	affiliation
Shaun Ayers	U.C. Davis
Jerry Bruns	Central Valley Regional Water Quality Control Board
Ron Churchill	Dept. Of Conservation, Div. of Mines and Geology
Rosemary Clark	Sacramento Regional County Sanitation District
Bill Croyle	Central Valley Regional Water Quality Control Board
Peter Dileanis	U.S. Geological Survey
Joe Domagalski	U.S. Geological Survey
Chris Foe	Central Valley Regional Water Quality Control Board
Tom Grovhoug	Larry Walker Associates
Rick Humphreys	State Water Resources Control Board
Mary James	Sacramento Regional County Sanitation District
G. Fred Lee	G.F. Lee & Associates
Michael Pickering	Brush Creek Mining and Development Company
Steve Schwarzbach	U.S. Fish & Wildlife Service
Darell Slotton	U.C. Davis
Chris Stathos	Keene Engineering
Claus Suverkropp	Larry Walker Associates
John Tomko	City of Sacramento
Roberta Tassey	Law Engineering
Rick Weaver	Tahoe National Forest

Table E-3. January 28, 1997 Final Public Project Meeting: Summary of Significant Comments and Responses.

comment	response
Discuss reliability of loading estimates	Discussion is added to final project report
Discuss factors contributing to uncertainty in loading estimates	Discussion is added to final project report
Address impacts of error of flow measurements for gages used in mercury study	Addressed in final project report
Incorporate average annual loads from SRWTP	Added to loading analyses in final project report
Discuss impact of bedload movement on loading estimates	Discussion is added to final project report
Calculate confidence limits for loading estimates/percentages	Additional loading analyses with confidence limits are included in final project report for validated data for most recent water year (1995)
Discuss potential that relative contributions from some areas may be more important during dry years	Discussion is added to final project report
Draft report text regarding reservoir impacts was inconsistent with conclusions presented in Final Project Meeting.	Corrected in final project report
Update discussion of potential health risks in reservoirs and streams; Incorporate discussion of more recent USEPA guidance.	Discussion is added to final project report
Recommend additional monitoring in reservoirs to assess potential health risks	Recommendation added to final project report
Identify unresolved questions concerning reservoir impacts and health risks, and relevance to other foothill reservoirs	Discussion is added to final project report
Recommend baseline monitoring in reservoirs to allow evaluation of program effectiveness	Recommendation added to final project report
Provide summary of "outgrowth issues"	Added to final project report (Table E-4)

Table E-4. January 28, 1997 Final Public Project Meeting: Summary of Significant Outgrowth Issues.

There is a possibility that POTWs (e.g. SRWTP) may have a disproportionate impact on bioavailable mercury if a high percentage of the mercury in effluent is organic or methylmercury compared to River. More information is needed on the proportion of bioavailable mercury in municipal wastewater.
Additional emphasis should be placed on protecting local watersheds, as well as protecting beneficial uses in the lower Sacramento River and the Delta.
Now that the Sacramento River above Verona has been identified as the source of the majority of mercury mass loading, similar mercury source identification studies should be pursued in that part of the watershed.
Additional studies are needed to determine the effect of different forms of mercury (e.g. elemental, cinnabar, etc.) on bioavailability.
Additional studies are needed to identify the contribution of bedload transport on mercury loads.
Should mercury sources be regulated on the basis on bioavailable mercury?
Additional studies are needed to evaluate potential health risks in Sierra foothill reservoirs.

MEETING PRESENTATION OUTLINE:

A. Project Overview

B. Study Design

C. Results

1. Mercury Sources and "Hotspots"
2. Reservoir Impacts
3. Mass Loading
4. Evaluation of the Study Approach

First Question and Answer Session

1a. J. Tomko: What is the source of loading data for Discovery Park?

C. Suverkropp: The Sacramento River Coordinated Monitoring Program (CMP) database supplied the data for Discovery Park on the American River, and the Veterans Bridge data upstream from Sacramento on the Sacramento River.

1b. Were these loads at Veteran's Bridge more than the loads downstream?

C. Suverkropp: The loads at Veterans Bridge were somewhat less than the sum of loads at the two main forks [the Sacramento River and the Feather River at Verona].

2. B. Croyle: How were the loads calculated, based on when the sample was taken, and what was the interval between samples?

C. Suverkropp: The water quality data used to perform the loading assessments were collected as composite samples and were not taken over a long period of time. We used ANCOVA [Analysis of Covariance] methods to analyze loads versus flow measurements from USGS. We characterized the relationship of the calculated daily loads for each sample event versus the flow of the each river. We used flow data for the exact time (or day) that we took the water quality samples, developed the regression analysis, and plugged monthly average flows into that regression curve to generate the monthly average mass loads. We then summed the monthly average loads to estimate the annual average loads.

3a. **J. Tomko: What is the average annual loading from the Sacramento Regional Wastewater Treatment Plant?**

C. Suverkropp: The Sacramento Regional Wastewater Treatment Plant (SRWTP) is in the middle of an assessment of mercury loading now. I am not sure what the final number is at this point. In the draft report, we used a mass balance approach with upstream and downstream data.

3b. **What do you mean by mass balance?**

C. Suverkropp: In the Draft Report, the SRWTP average annual load was estimated using annual averages from long term data sets from the CMP for sites above and below the treatment plant. The SRWTP annual average was estimated as the average difference between the sites [Freeport and River Mile 44, upstream and downstream of the SRWTP, respectively].

We do have an older analysis that comes out quite a bit higher than estimated by the mass balance, but it is based on some not-so-reliable data and based on some flow assumptions for the plant that are not really accurate. That is why we are trying to get new [flow and quality] data. We expect loads to come out lower than estimated by the initial analysis.

4. **C. Foe: About the pie diagram that shows loads from the different watersheds: How does this diagram compare to a similar pie diagram that compared just TSS loads (sediment loads) for sections of the watershed?**

C. Suverkropp: I suspect it would be weighted even a little more towards the Sacramento River. I remember that the average TSS [suspended solids] concentrations were proportionally higher in the Sacramento River than the mercury concentrations were. We have seen a fairly strong positive correlation in Sacramento between total mercury and TSS in the CMP data. It wouldn't be surprising if the proportional loads of mercury and TSS were fairly similar. The loading proportions are heavily influenced, but not totally controlled, by the proportion of flows.

5a. **B. Croyle: What about exceedances in the [treatment plant effluent] compared to the Sacramento River? You mentioned that these exceeded the criterion 20 to 30% of the time?**

T. Grovhoug: The Sacramento River exceeds 12 ppt 20-30% of the time at Freeport, not the effluent.

5b. **How much work would need to be done in order to bring those amounts down at Freeport? Can you bring Freeport concentrations down by controlling mercury in an area that contributes 2% of the load?**

C. Suverkropp: One of the main conclusions of this first portion of the study is that it is difficult, if not impossible.

T. Grovhoug: We can determine statistically, using the long term average approach, how far we need to bring the distribution [of mercury concentrations in the Sacramento River] down. You can play with what the long term average needs to be in the river to reduce the exceedances to an acceptable level.

B. Croyle: That plays into the implementation of any corrective action, because if you are looking for the average over the year, the flood impact may compute a little bit differently with the reservoir influences or uncontrolled gold mining areas. If the Sacramento [River] is the big loader, obviously not a lot of work is going to be done anywhere else, unless its cost-effective or is going to produce some benefit at Freeport.

T. Grovhoug: That is one of the things we would like to talk about. Whether it is appropriate to put all your eggs in one basket to just change water quality at Freeport, or whether there are there other things that can be done in the system that provide more positive benefits.

C. Suverkropp: We will talk about that a little more in the control measure evaluations.

6. **S. Schwarzbach: Do you have a feel for the amount of error in the flow measurements used to calculate the loads? If the error of the Verona flow measurement is 2%, it will be just as much as on the whole control project on the Yuba River. How big is that error?**

C. Suverkropp: It is difficult to characterize that with the amount of data that we have so far. I don't think there is very much error due to flow measurements and, to a large degree, flows determine what the loading percentages are. Based on the 10 or 11 data points we have for water quality, obviously there is going to be a good percentage of error around those annual average estimates. I suspect they would be larger than 2%.

7a. **J. Domagalski: What if you tried a kind of verification exercise with the 10-11 points for the regression analysis for the mercury? If you took something that was a surrogate for mercury (e.g. total suspended sediments), and using those same points, go through the exercise and compare that with long term averages for suspended sediment that you could get from the Freeport station and see how close you could get to simulating what is actually there.**

C. Suverkropp: We did that exercise to some degree in comparing the loads of the Sacramento River and the Feather River portions to the loads estimated at Freeport using the same methods with a longer-term data set. The estimates agree pretty well on that basis.

J. Domagalski: In other words, you can use the regression method to simulate the loads of suspended sediments at Freeport, as a means of validating the method.

C. Suverkropp: We can certainly try that. It would involve quite a bit more analysis.

7b. **J. Domagalski: What happens if you include the Yolo causeway in the mass balance?**

C. Suverkropp: We did a little bit of an estimate for that based on mass balance using the Feather River data. The estimated mass load that goes out into the Yolo Bypass doesn't clean up the discrepancy in the mass balance. Loading to the Yolo Bypass is episodic and it is a difficult to estimate meaningful annual average estimates: there are some years with no flow, and these lower the annual averages. However, we could use the 1995 data as a test case. The water that flows into the

Bypass [at the Sacramento Weir] should be the same quality as at the Freeport station.

8. **J. Domagalski to Darell Slotton: What would you expect to see in the Sacramento River for macroinvertebrates?**

D. Slotton: We are anxious to do that work. We don't have any data at this point. The work really cries out to be done.

J. Domagalski: We took some samples recently in the upper Sacramento River, up near Red Bluff and Redding. We don't have the results yet, but we will let you know when we get that data.

D. Slotton: We are planning to sample the whole area, and if we find anything interesting in the lower river, to move up into that watershed.

9. **P. Dileanis: Did you try to calculate a range of loading based on standard error in your regressions?**

C. Suverkropp: That will probably be something that we add to the final report. There are a few ways we might approach that. Because we use the long term USGS monthly averages to sum up yearly averages, it entails quite a bit of effort to get at the error associated with those long-term USGS averages.

P. Dileanis: I don't know about the USGS and Verona data specifically, but for a gauge like that, flow data is probably within 3-5% of what is calculated for specific data points.

10. **R. Humphreys to Darell Slotton: A lot of times you get into discussions about what form of mercury is more bioavailable. Are you seeing differences in bioavailability depending upon what form the mercury is in and what the biosystem is like? Does it matter whether the mercury is elemental mercury or cinnabar?**

D. Slotton: That is where the best research is heading right now. I think that what is going on in the upper watersheds is that you just don't have the environmental conditions necessary to support methylation. You have cold clear water that is moving, and a low population of methylating bacteria. Not until you get into the reservoirs or downstream do you get the methylating bacteria. I think its also a difference between the elemental mercury that is spread all through the Sierra Nevada as compared to cinnabar in the Coast Range, which is much more bound up. Its not clear what the fate is of all that elemental mercury that's been spread through the Sierra Nevada, whether it immediately bound itself up in sulfides or whether its more bioavailable. Even though its a smaller fraction of what is coming into the Delta, it may be more important.

11. **C. Foe: In the draft report on page 17 in the summary items, it was reported that reservoir impacts observed for Englebright were not consistently observed at other reservoirs.**

C. Suverkropp: There was a typographical error in the report. Because it was an unexpected result, I didn't fully appreciate the consistency of the pattern in the biota data. This will be correctly reported in the final draft.

D. Slotton: It was a big surprise that there were not higher amounts of bioavailable mercury downstream under normal flow conditions. We found that the mercury stays in the reservoir.

12. **C. Foe: Trout don't seem to be very good bioaccumulators when compared to bass. Can you estimate the level that would be in bass in foothill reservoirs? Would there be a human health problem [with the mercury concentrations] in bass?**

D. Slotton: Bass appear to be better indicators of mercury because they live in an environment that has more methylmercury. I think that if you stuck the trout into the reservoirs that they would have higher mercury as well. I think that more work needs to be done in the foothill reservoir to characterize the fish tissue mercury all throughout that area. That is why they [bass] could have higher mercury levels than trout.

C. Foe: Besides bass, what fish would you evaluate for mercury?

D. Slotton: This is really interesting. This was too small a dataset to really sink our teeth into. All fish in Englebright Reservoir were at or above guideline [0.5 ppt mercury in edible tissue]. This was a small sample, but the two bass that were analyzed were 11 inch two year old fish, and probably eating benthic invertebrates, rather than being piscivorous. The mercury was at pretty high levels for fish at that stage. The other three fish were herbivorous species; we had hardhead, which is a native vegetarian species, and carp, which had been low everywhere else, but was over the health guideline [in the Englebright sample]. Sacramento sucker, a fish that usually has low mercury concentrations, also had high mercury levels. We were disappointed that we could not get some large trophy-size bass; it would be interesting to see the numbers.

C. Foe: Would you expect high numbers in catfish?

D. Slotton: If anything is going to be elevated, yes.

C. Foe: What about crayfish?

D. Slotton: I didn't include crayfish [in the report], but we've got a side project going with crayfish from a number of these sites. They seem to be the highest order consumer of the whole bunch. They must rely largely on [dead] fish, so the study is testing crayfish at a number of sites. Crayfish appear to be at levels similar to or greater than the fish from the same sites.

13. **B. Croyle: Were the mercury levels in fish and crayfish in the upper watershed greater than the guidelines?**

D. Slotton: We didn't see any crayfish or fish above the [FDA and MIS] guideline levels in the upper watershed. The largest brown trout in the study (caught by Shaun Ayers in the American River) was only 0.3 ppm. In other watersheds, e.g. the Yuba system, trout and squawfish were the highest, but still well below the others downstream.

14. **J. Bruns to D. Slotton: You were talking about pinpointing sources. You were saying that mercury sources are generally spread out based on the data. How**

do you know there is not one upstream source that causes all the tissue values to be elevated?

D. Slotton: We have been thinking about that question.

C. Suverkropp: Would you expect to see a typical point-source type of signature in the biota data?

D. Slotton: We are isolating sources on a stream by stream basis. We can isolate to the tributary level, but we can't really go beyond that, except to see where it drops off within a specific tributary.

S. Ayers: A good example of that was seen in our Marsh Creek Reservoir, where we had a single point source. At Marsh Creek Reservoir, the level of mercury in an organism dropped off because of dilution as we moved downstream. We didn't observe that kind of drop-off in biotic mercury for this study: mercury levels increased as we went downstream, suggesting additional loading downstream.

D. Slotton: In some of our Cache Creek work, we observed order of magnitude decreases in biotic mercury as we moved away from point sources.

C. Stathos: Historically, mercury was used in a pretty wide-spread fashion. Millsites would come and go throughout the area. Mercury was used both in the waterway and up on the banks.

15. **C. Stathos: How much are rainfall events calculated into the data? Do you find that during periods of rain and immediately after you get higher loads from the bank washing?**

T. Grovhoug: In the Sacramento River we see higher mercury concentrations occurring with high stream flow and sediment movement through the system.

C. Suverkropp: Both loads and concentrations increase when the flows go up.

T. Grovhoug: We do have the water column data in the report. I remember seeing a high of 60 or 70 ng/L of mercury in one of the arms of Englebright during one of the storm events. That's when all of the loading happens, during the episodic events.

C. Stathos: That's what I would expect to happen. The mercury was often used up on the banks, off of the watercourse, rather than in the waterway. There could be hot spots that eventually could be found if you do a lot of sampling.

D. Slotton: I expect that most of that has already moved into the streambed and is moving downstream.

C. Suverkropp: There is some evidence that there are some hydraulic mine tailings remaining from the Gold Rush period in the study area watersheds.

16. C. Foe: **All of the mercury loading [analysis] is basically water column-based. Do you have an [idea] of what mercury loading would look like if you incorporated bedload movement?**

C. Suverkropp: We can characterize the proportion of mercury in sediments by looking at the mercury concentrations in suspended solids. When we've done that in the past, we've gotten very consistent numbers, and the mercury concentration in sediments doesn't change so much with high flows. The mercury concentrations in suspended sediments stay fairly constant compared with other water quality parameters.

J. Domagalski: Randall Dinehart of USGS specializes in bedload transport. You actually could do that type of analysis given the right sampling and techniques to characterize the amount of sediment moving as bedload as a separate study all by itself. I don't think you could use your current dataset to tease out what is going on. Potentially, bedload transport could be significant.

T. Grovhoug: We do depth integrated sampling, but it doesn't get at bedload movement.

C. Foe: One of the most captivating things about the report is the pie diagram. I think that we have all been asking about the uncertainty of those numbers. The reason I bring up the bedload issue is because it adds to the uncertainty of the numbers. I think the numbers are great, but I don't know whether to believe them.

B. Croyle: When we had the first TAC meeting, there was discussion that we should use sediment monitoring in the study. It was recognized that there were other possible transport mechanisms or sources that you can assess by different ways, but that the budget for the project didn't have enough room to address all of the possible concerns.

T. Grovhoug: C. Foe's point was that we need to acknowledge the uncertainty in the report because we haven't done that.

D. Slotton: Chris, I think that this all comes back to the research we're heading into. We have been talking about looking at the bioavailability of these minerals, and the different forms that mercury is in. I think that the vast majority of the mercury—literally in chunks—in the bedload is not causing the problem, but we need to show it.

J. Domagalski: This potential model could be correct. In the final reports we need to consider the degree of uncertainty because it is going to affect how we see potential remediation. We need some independent verification that the numbers add up like we see, and if so, following up with additional work upstream with the biota, to characterize what those potential sources are.

C. Suverkropp: We will address the uncertainty more clearly in the final report.

B. Croyle: One of the questions that we're attempting to answer is: Is this a good approach to take in the basin? I think that this is a valuable project, and that it is a stepping stone to some of the work up in Cache Creek and all the basins up the Valley. It seems that, based on what we are learning, there are some components that need to be added to these kinds of multi-media assessments. Biology has been added, and it seems like its a very important part of almost any work we do in the future. We need more of the historical perspective to see if there are ways to get at where the sources might be, based on mine maps, mine inventories, or state geologist reports. To move this type of research forward, we need to incorporate other types of information that are available. Everyone here has different levels of concern with what we're seeing here because of where this might lead us. I think this is a good demonstration or pilot project, and it will provide a lot of answers, but it also raises a lot of questions. We need more resources to be able to address [some of these] questions.

17. **<u>R. Humphreys</u>: About the bioaccumulation of biota diagram: When you read the study, you see how much mercury these critters accumulate over the year when the streams are mostly running nice and clear and cold, whereas you only see these big flushing events where you have mercury in the water column occur only a very few times during the year. This raises the question: is the methylation occurring when the mercury is part of the bedload in the upper watershed?**

<u>D. Slotton</u>: That's a great point: that you shouldn't construe mass loading from the biotic information. Its a technique to get at one tributary versus another as a potential source, although usually the biotic mercury is proportional to the total mercury coming down in the given streams. Obviously, during the huge storm flows, that's when the mass of the mercury is moving.

<u>C. Suverkropp</u>: The biota component is much more time dependent than the loading component.

19a. **<u>S. Schwarzbach</u>: I was little confused about the conclusions on reservoir effects. There seems to be a lot of ambiguity with the reservoir data. Englebright Reservoir seems to be the best-characterized reservoir above and below. I am concerned about the conclusions that might be drawn by others reading this document if they only read the conclusions about all reservoirs in the Sierra: for example there are big differences in reservoirs and in water years. For instance, Comanche Reservoir would be a very different place than Englebright Reservoir. I think a lot of *caveats* need to be presented with the reservoir information. You need to identify future questions that are unresolved.**

<u>D. Slotton</u>: The source of that confusion was that the reservoir data was like a negative result. We were expecting to see a huge spike in the biota right downstream of these reservoirs. Not only wasn't there a big spike, it was often significantly lower than upstream or in the reservoirs. It was a big surprise to us, but it doesn't imply that there is not a lot of mercury moving through these reservoirs.

19b. **<u>S. Schwarzbach</u>: I also wonder about water year variations: a dry year vs. a wet year like this year, and using average annual loads. How do you get at the possibility that the relative contribution from some areas during dry years may be more important?**

<u>D. Slotton</u>: Within the streams of the upper watershed, we had the highest [biotic mercury] numbers in 1994, when the water wasn't moving, and the lowest numbers during the big storm years. The results of our work in the coast range show the opposite effect down in the reservoirs themselves.

S. Schwarzbach: Biologically, dry year data may be the most significant, but its the flow data that drives the calculations of the relative importance of loads. It is the big flows that drive the decision making.

D. Slotton: We need to isolate which small fraction of the total mercury is causing the trouble downstream. I think the biota portion of the study is getting at that proportion.

C. Foe: We also need to say that we want to protect the [local] watersheds in their own right and that we also want to protect the Delta. These high flows may bring large amounts of mercury down into the Delta, and we have fish advisories down there.

C. Suverkropp: That's why there was the emphasis on the mass loading.

B. Croyle: We need to be very careful when we are looking at these reservoirs. I think that the information that you've done on Davis Creek Reservoir is interesting, but that Englebright is a scary place to try to do this kind of work because of the hydraulics of the system. You have a large cold water reservoir and in one major arm a lot of that water is flow-through, so the operation of that reservoir is going to be a lot different than, say, Camp Far West which is down-gradient of a high mercury area. ...or of Lake Oroville, which is much larger. So when we try to draw conclusions about what is happening at Englebright, we have to keep it in mind that Englebright is not the perfect model.

D. Slotton: We do have some information downstream of all the major reservoirs, and we don't see any big spike increases in bioavailability downstream.

C. Suverkropp: Even though Englebright is the best characterized reservoir in this study, and the biota data is generally consistent for the other reservoirs, we have to be careful about extrapolating these results to other reservoirs with different flow regimes, surface area, depth, bottom area, and other water quality characteristics.

[10 minute break]

D. Control Measure Evaluations

- Methods to Evaluate Strategies
- Candidate Control Measures for Study Area-
- Evaluation Criteria
- Mercury Control Strategy Rankings

E. Implementation Plan Program Elements

- Public Outreach and Education (broad and targeted)
- Mercury Collection and Recycling

- Institutional Plan
- Funding Alternatives

Final Question and Answer Session

1. <u>J. Domagalski</u>: **Would there be any difference in the control strategy ranking if the load estimate came out differently? Say the load estimates at Freeport are due to a pipeline in the Yuba and Feather Rivers, so that it is isolated in the gold mining region. It seems like the control strategies might not be too different from what you have here because of the diffuse and wide spread nature of the sources.**

   <u>C. Suverkropp</u>: They would shift around a little bit. Some of the strategies would be expected to get at different percentages of the sources. This would effect the equation somewhat, but the load proportion affects only part of the overall rankings. Since the rankings are weighted towards the downstream and local benefits, it could have a fairly large impact.

2a. <u>S. Schwarzbach</u>: **Do we have reliable data from effluent or mass balance calculations above and below Freeport on methylmercury or organic mercury loading from the [wastewater treatment] plant?**

   <u>C. Suverkropp</u>: I don't think that the treatment plant is monitoring methylmercury in the effluent.

   <u>Rosemary Clark (SRCSD)</u>: No.

2b. <u>S. Schwarzbach</u>: **If we could have a methylmercury control strategy rather than a total mercury control strategy, would that change how we do the control options?**

   <u>C. Suverkropp</u>: It is something that we looked at indirectly. It relates back to why we emphasized the mass loading. Even if we knew exactly what proportion of the mercury is bioavailable in the study area, and when it becomes bioavailable, I'm not sure that it makes any difference in evaluating the control strategies. Even if the mercury is not bioavailable in the upper watershed, it may become bioavailable lower in the watershed. We could control methylmercury in the upper watershed and not solve the problem in the lower watershed, if the methylmercury is not a large percentage of the total mercury in the upper watershed.

   <u>S. Schwarzbach</u>: I guess you wouldn't be able to control methylmercury in the upper watershed. To answer my own question, I think it would result in a different strategy. Not that I don't like your recycling program, Bill, I think you should go for it. But it may change the way other things fall out if only a few percent of the load that is coming down is ultimately going to be converted to methylmercury. If the proportion of organic mercury coming from the plant is much higher than in the river, it may account for a much larger percentage of the bioavailable mercury, even though it is a relatively small fraction of the total load. You might look at the whole strategy a little differently in that case.

C. Suverkropp: I don't have the information necessary to answer that question right now. If you know of anyone that is monitoring methylmercury in their effluent, let me know.

S. Schwarzbach: I think San Jose is doing methylmercury monitoring.

3a. J. Tomko: Does the recycling program go after existing current gold mining operations? Does it go after historical mercury remaining on the hillsides?

C. Suverkropp: The recycling program is taking advantage of the fact that even if they (gold miners) do not seek it out specifically, when they see it, they collect mercury remaining from the historical gold mining operations because the mercury acts as a "sponge" for gold that's out there. I don't think they are allowed to use mercury up there anymore, so most of it is from the historical mining operations. Its being pulled directly out of the streambeds primarily, and the near-riparian zone.

3b. Is there an estimate of the percentage of the total load that might be collected using this approach?

C. Suverkropp: We are not sure, but the stuff that does get pulled out is the most mobile and transportable mercury in the system.

3c. So how did you get the kilograms/dollar?

C. Suverkropp: The absolute value of kilograms/dollar was not calculated. The alternative control measures were ranked on a relative basis. Professional judgment played a significant role in this evaluation to some degree. We have good information that quite a few kilograms of mercury would probably be recovered, maybe even hundreds of kilograms in the initial phases. Looking at the cost of this strategy compared to the costs of implementing the other strategies, we came to the conclusion that the recycling program would result in a relatively low cost to remove substantial amounts of mercury.

R. Humphreys : You have to realize that you have potential to use a 3000-person workforce for free. There is a lot of anecdotal evidence of how much mercury is up there, and you can put together scenarios about how much you are likely to recover, but you really don't know until you start collecting it. You have to look at from the perspective that we only have to spend a little money on management to get all these people out there collecting mercury for us. Whereas the alternative for some of these other strategies is to spend the money on management and then contract out what amounts to a construction project. And again, we can't say how much mercury we're going to get at the end of that construction project, but we can say that its going to cost a whole lot more money. We are put into an unfortunate situation because we cannot predict how well it is going to work until we do it.

C. Suverkropp: We only have enough information to provide a very approximate number for any of those strategies.

D. Slotton: We know that there *is* mercury in the watershed, but cannot quantify it.

R. Humphreys : We've speculated about how many shipping containers we might need the first year we offered program, and whether we would see a big spike that would tail off to some predictable level. The problem in dealing with something like this is that you really don't have a clue about the outcome, and you're faced with the choice of studying to get a better idea or just going ahead and doing it.

B. Croyle: I think that's part of the pilot phase...getting what's in the garages out and to the recyclers, and in the process building the relationships. We heard from miners that they actively do not dredge areas with mercury because they don't want to deal with it—either the possible damage to their equipment or the possibility of getting "tagged". If there was opportunity or financial incentive, they would go after it. People are talking about ounces of mercury in easily accessible pools.

4. **C. Foe: If you develop the mercury recycling program you ought to get baseline data. Why run a program without the ability to evaluate its success? On a related topic, do LWA and UC Davis feel comfortable enough with the fish tissue data to recommend that a human health study be conducted in the Sierra foothills to see if there are some fish species up there that warrant having these reservoirs posted? It could run in tandem with the mercury baseline study. It will not help us control the mercury, but will help us control the hazard.**

C. Suverkropp: The Sierra reservoirs might actually be the best opportunity for generating some real improvements. Those reservoirs are directly downstream from where we would be collecting most of the mercury. You're recommending that we should do a baseline study to see if we are actually having a beneficial impact there.

S. Schwarzbach: If you were really going to look at the human health risk in the Sierra Foothills, you would look at the small streams with historic mining that have small reservoirs or ponds with warm water recreational fisheries. Those types of places all over the Sierras, and are more likely to be the areas of methylation.

C. Foe: I remind you, in the project overview, you wrote that the number one objective was to evaluate the potential for health risks. The study would be remiss if at the end you don't either say that there is no health problem, or that there is potentially a health problem and recommend some follow up. If this is your top objective, it seems that you can't sidestep this issue. You need to discuss the potential health risk in the report.

C. Suverkropp: We did state in the presentation, that although there don't appear to be direct health risks in the streams of the upper watershed, there is a strong possibility of some risks in Englebright based on Darell's data. And if that's true in Englebright, it may be more likely in other reservoirs that are even more amenable to methylation of mercury.

G. Fred Lee: You are using badly outdated data on health risk. If it all goes back to 1972 Blue Book, those numbers were not intended to be used as they are being used here. We have much more up-to-date data, and we use risk-based approaches where you have to consider somewhere around a tenth of a milligram per kilogram for one meal per week as the risk value that you should consider for pregnant women. That has to be factored in. The statements that you have no health risk, I think are wrong. They are flat-out wrong. Not according to what we know today. Then you have to consider one meal per month, six and a half grams per day gives you a health-based risk of about six tenths of a mg/kg. The FDA says 1 mg/kg. FDA says they believe in that number and that the EPA is wrong, but EPA will prevail. So we need to post those areas where you have concentrations—in fact almost all your fish—above 0.1 mg/kg. They need to be posted by DHS. I haven't gone back to look at DHS numbers, but it looks like that may be badly out of date as well.

C. Suverkropp: Posting those areas would probably require a much more comprehensive health risk assessment…

G. F. Lee: These things are being widely done. They are being done in the San Francisco Bay and other place. We just need to bring that into this process. EPA has a lot of information out there that is not in this process.

T. Grovhoug: This is a currently a hot topic at EPA…

G. F. Lee: We have good stuff on these numbers. I'm following it very closely and this process as its put forth in the draft report is out of date with respect to health.

T. Grovhoug: I understand that EPA is using an action level or an alert level of 0.14 mg/kg.

G. F. Lee: That's San Francisco Bay, for one meal a week. That number is one that has held pretty well across the country, depending on what you assume for consumption. Your report doesn't mention the four volumes that EPA has put out discussing these issues. The information from EPA should be included.

T. Grovhoug: But I would not go so far as to recommend posting all of the reservoirs and streams because they exceed that limit, because it is still a controversial number. The trend in tissue-based mercury limits is downward. As I mentioned, concern for bioaccumulation and biomagnification in wildlife is a big issue for the Great Lakes, and those mercury limits get very small. But that is a valid point that we need to address in the final report.

J. Bruns: I think we should include that. Should we include a recommendation that further collection of data should be done in these reservoirs to determine whether these reservoirs should be posted or not?

T. Grovhoug: I think it goes hand in hand with Chris' [Foe] baseline idea. If we are advocating the recycling program, then we could kill two birds with one stone to get at both the health risk issue and the baseline data issue.

J. Bruns: Further collection of data could be done, but whether reservoirs need to be posted or not is a different issue. The issue of health risks in the reservoirs is a stand alone thing. We need to find out what kind of information OEHHA needs to make their determination on reservoirs and postings. It seems that if we concluded from the data that there is a potential risk, that the report should recommend that more fish need to be collected, and we need to ask OEHHA what they think about it. It seems that should be a recommendation of the report.

B. Croyle: Its more than just collecting fish, though. You need to do fish consumption surveys, determine which places need to be looked at, what fish, as part of the risk assessment. It sounds like there are a number of things that we would like to see move forward, and this is just one of them. Another issue is in using this type of approach up in moving up the basin, how we should use the assessment techniques in other areas of the Sacramento River, especially if we are getting a big load of mercury from upstream. The methylmercury issue that Steve [Schwarzbach] brought up is interesting, because Chris [Foe] and others in this room are trying to figure out how we move from a total regulatory limit of 0.012 µg/L and what it means biologically to the system. I'm wondering if the methylmercury question in point sources starts that process. We should try to address that.

S. Schwarzbach: Further down in the watershed in the bay itself, the area where the most methylation occurs is in the intertidal sediments. Even in those sediments, the most methylmercury you will see in a hot spot is around 3%, and its usually around 1% or less. Only a certain fraction of total mercury is eventually going to be converted to methylmercury. If you could interrupt a big slug of methylmercury right away, that would have far more value than if you would interrupt maybe 20 times more total mercury, in terms of bio-risk further down in the system. If there is a way to do it. I am not familiar with the San Jose data, but they have tried to better characterize what is in their waste stream because of severe limitations on the treatment plant, and they have improved their measurements to show that they are discharging much less mercury than people thought they were. But in terms of pollutant trading, I think its probably true that a kilogram of mercury in sewage effluent is not the same as a kilogram in Yuba River water.

G. F. Lee: We are a long way away from defining how to develop a meaningful control program yet, because we don't understand the system. We have a pretty good idea that there is a problem up where you are studying. That fine. That needs to be addressed. But what that relates to downstream nobody knows.

R. Humphreys : What the recycling does, is that it pulls mercury out of the system. You can tell people how much you are removing, but how that effects the overall system is a complete unknown. We are assuming that recycling will do some good to reduce the overall source in the area.

5. **S. Schwarzbach: If you are going to prioritize a recycling effort, would you do it above or below the reservoirs?**

R. Humphreys : For the recycling program, you do it wherever the dredgers want to do it. They are quite independent. While they are willing to bring the mercury in, as Bill and I have found out over the years, you have to develop a high level of trust with not a lot of demands. Because we are dealing with volunteers who don't initially trust state workers anyway, you're making a lot of progress just to get them to recycle the mercury.

T. Grovhoug: It is one of the inherent values of the program. If you can set it up, its a real positive, watershed management-type voluntary approach that's actually doing good if its taking mercury out of the system. There's no getting around that its going to provide some benefit. It also highlights mercury as a concern in the watershed. Its a success story. It does raise this question of trading benefits above a reservoir or up to a dam versus our ability to control mercury in the mainstem of the Sacrament River. That's an interesting policy question. Is it feasible to set up a program that allows Sacramento Regional [County Sanitation District] to pay to improve water quality somewhere else, instead of paying for a super-sophisticated treatment process that's too expensive for the water quality benefits it might provide?

R. Humphreys : In addition to addressing the project goals, this has raised a lot of interesting issues. It might be worthwhile to provide a summary of these outgrowth issues in the final report.

9. **T. Grovhoug: Should we be monitoring methylmercury in the water column?**

S. Schwarzbach: I think so.

B. Croyle: It seems that we need to address that issue, but you are asking the discharger to do more work, when what they are really trying to do is meet some guideline. You're trying to design a special study to determine if there is some other number that we can use that's more biologically relevant instead of the 12 ng/L number. To make that transition, it seems that everybody has to agree on what you're trying to accomplish.

D. Slotton: That is the whole point of the bioindicators; to provide a surrogate for methylmercury concentrations integrated over time. But it is hard to quantify that relationship.

C. Foe: I didn't see that there was much of a correlation of methylmercury to biotic availability.

D. Slotton: Its hard to get enough water samples to characterize the relationship in running water.

G. F. Lee: I would agree; we don't understand methylmercury coupling very well. We need lab studies to better define the kinds of things that you're pointing out. You have an interesting technique with tremendous potential, but what it means yet is not understood, and how to use it is not understood. You need to investigate it under controlled conditions.

The meeting adjourned at 12:05 PM.

APPENDIX F:

PRINTOUT OF PROJECT WATER QUALITY DATA TRANSMITTED TO STORET

Sacramento River
Mercury Control Planning Project:
Data Transmitted to STORET

Location	STORET Station number	Sample Date & Time	Sample Type	total Hg (ng/L)	0.2µ filtered Hg (ng/L)	total MeHg (ng/L)	0.2µ filtered MeHg (ng/L)	TSS (mg/L)	pH	Temp. (°C)	DO (mg/L)	EC (µS/cm)
Feather R. at Yuba City	SMP-FEAR-YBC-W1	3/23/95 12:10	5 pt x-sec	10.79	3.19	0.102	0.058	40.0	7.05	8.20	9.30	76.0
Yuba R. at Marysville	SMP-YUBR-MVL-W1	3/23/95 11:21	6 pt x-sec	17.59	4.52	0.121	0.058	42.0	7.11	8.80	9.90	66.0
Feather R. at Yuba City	SMP-FEAR-YBC-W1	4/26/95 11:20	13 pt x-sec	8.44	2.80			25.0	7.50	13.70	10.70	86.0
Feather R. at Nicolaus	SMP-FEAR-NIC-W1	5/4/95 11:25	5 pt x-sec	16.35	2.48			49.0	6.78	13.21	10.34	78.0
Sacramento R. at Ord Bend	SMP-SACR-ORD-W1	5/3/95 12:12	5 pt x-sec	16.84	2.79			100.0	7.16	12.34	10.60	104.0
Yuba R. at Marysville	SMP-YUBR-MVL-W1	4/26/95 12:10	9 pt x-sec	6.71	2.78			12.0	7.60	11.00	12.20	68.0
Feather R. at Yuba City	SMP-FEAR-YBC-W1	5/31/95 11:06	10 pt x-sec	7.07	1.86			21.0	6.42	15.30		72.0
Feather R. at Verona	SMP-FEAR-VRN-W1	6/1/95 10:24	15 pt x-sec	8.69	2.03			20.0	7.61	15.20		62.0
Sacramento R. above Verona	SMP-SACR-VRN-W1	6/1/95 11:30	5 pt x-sec	14.94	3.11			46.0		20.20		182.0
Yuba R. at Marysville	SMP-YUBR-MVL-W1	5/31/95 10:17	6 pt x-sec	7.07	1.52			24.0	6.42	12.70		52.0
Yuba R. at Marysville	SMP-YUBR-MVL-W1	5/31/95 11:45	6 pt x-sec	5.83	1.36			22.0	6.45	13.20		50.0
Yuba R. at Marysville	SMP-YUBR-MVL-W1	5/31/95 13:19	6 pt x-sec	6.29	1.60			22.0	6.50	14.00		50.0
Feather R. at Yuba City	SMP-FEAR-YBC-W1	7/17/95 10:52	7 pt x-sec	4.24	1.20			12.0	7.17	21.42	9.44	90.4
Feather R. at Verona	SMP-FEAR-VRN-W1	7/17/95 13:20	8 pt x-sec	5.58	1.37			12.0	7.26	20.38	9.65	82.8
Sacramento R. above Verona	SMP-SACR-VRN-W1	7/17/95 14:00	9 pt x-sec	22.82	1.07			240.0	7.37	20.89	9.38	119.0
Yuba R. at Marysville	SMP-YUBR-MVL-W1	7/17/95 10:07	9 pt x-sec	7.20	2.17			8.0	6.99	13.17	11.03	56.2
Feather R. at Verona	SMP-FEAR-VRN-W1	8/24/95 12:53	5 pt x-sec	6.95	1.75			12.0		19.60	9.72	73.6
Feather R. at Yuba City	SMP-FEAR-YBC-W1	8/24/95 10:37	5 pt x-sec	4.73	1.67			13.0		18.30	9.94	72.0
Sacramento R. above Verona	SMP-SACR-VRN-W1	8/24/95 13:43	9 pt x-sec	9.50	1.33			56.0		20.40	9.00	152.0
Yuba R. at Marysville	SMP-YUBR-MVL-W1	8/24/95 9:54	9 pt x-sec	3.63	1.50			3.0		13.13	10.40	67.0
Feather R. at Yuba City	SMP-FEAR-YBC-W1	10/5/95 11:00	12 pt x-sec	4.90	1.69			16.0	7.47	13.17	10.90	64.5
Feather R. at Verona	SMP-FEAR-VRN-W1	10/5/95 16:20	5 pt x-sec	5.50	0.93			15.0	7.55	14.95	10.70	68.2
Sacramento R. above Verona	SMP-SACR-VRN-W1	10/5/95 15:40	9 pt x-sec	7.24	1.24			39.0	7.84	16.90	9.48	150.0
Yuba R. at Marysville	SMP-YUBR-MVL-W1	10/5/95 12:00	9 pt x-sec	2.71	1.18			3.0	7.44	13.39	10.17	78.9
Feather R. at Yuba City	SMP-FEAR-YBC-W1	12/14/95 11:50	10 pt x-sec	11.70	11.17			30.0	7.18	11.21	10.32	72.4
Feather R. at Verona	SMP-FEAR-VRN-W1	12/14/95 14:15	15 pt x-sec	19.95	1.69			50.0	7.20	11.29	10.06	73.6
Sacramento R. above Verona	SMP-SACR-VRN-W1	12/14/95 15:00	9 pt x-sec	136.29	5.50			750.0	7.14	12.37	8.10	116.2
Yuba R. at Marysville	SMP-YUBR-MVL-W1	12/14/95 11:10	9 pt x-sec	39.96	3.69			12.0	7.19	10.16	10.83	68.7
Feather R. at Nicolaus	SMP-FEAR-NIC-W1	1/25/96 16:05	15 pt x-sec	42.29	5.69			90.0	7.34	9.64	12.04	73.6
Feather R. at Yuba City	SMP-FEAR-YBC-W1	1/25/96 11:40	15 pt x-sec	7.84	2.13			26.0	7.37	8.88	12.12	77.3
Sacramento R. above Verona	SMP-SACR-VRN-W1	1/25/96 14:45	9 pt x-sec	21.96	4.36			100.0	5.73	8.49	11.88	158.0
Yuba R. at Marysville	SMP-YUBR-MVL-W1	1/25/96 11:00	9 pt x-sec	25.03	5.63			22.0	7.31	8.76	12.48	74.2
Feather R. at Verona	SMP-FEAR-VRN-W1	2/1/96 14:10	15 pt x-sec	10.41	3.31			22.0	7.32	9.86	11.74	75.5
Feather R. at Yuba City	SMP-FEAR-YBC-W1	2/1/96 10:55	15 pt x-sec	8.59	1.08			26.0	7.28	9.75	11.82	77.4
Sacramento R. above Verona	SMP-SACR-VRN-W1	2/1/96 13:22	9 pt x-sec	15.05	2.70			74.0	7.52	9.05	11.10	77.4
Yuba R. at Marysville	SMP-YUBR-MVL-W1	2/1/96 9:50	9 pt x-sec	9.51	3.87			9.5	7.21	8.60	12.19	66.2
Bridgeport	SMP-YRSF-BPT-W1	3/20/95 13:20	grab	68.54	4.22	0.177	0.062	240.0	7.40	11.10		
Englebright	SMP-YUBR-ENG-W1	3/20/95 8:30	grab	5.47	1.97	0.039	0.012	8.0	7.40	11.60		

Sacramento River
Mercury Control Planning Project:
Data Transmitted to STORET

Location	STORET Station number	Sample Date & Time	Sample Type	total Hg (ng/L)	0.2µ filtered Hg (ng/L)	total MeHg (ng/L)	0.2µ filtered MeHg (ng/L)	TSS (mg/L)	pH	Temp. (°C)	DO (mg/L)	EC (µS/cm)
M.F. Yuba R. below Colgate	SMP-YRMF-COL-W1	3/20/95 11:00	grab	4.48	0.94	0.012	0.042	12.0	7.30	10.20		
Bridgeport	SMP-YRSF-BPT-W1	4/18/95 12:45	grab	7.68	1.88	0.114	0.071	18.0	7.76	9.29	11.30	59.0
Bridgeport	SMP-YRSF-BPT-W1	4/18/95 13:50	grab	7.45	1.85			16.0	7.78	9.42	11.22	59.0
Bridgeport	SMP-YRSF-BPT-W1	4/18/95 14:45	grab	6.55	1.80			16.0	7.77	9.52	11.17	59.0
Englebright	SMP-YUBR-ENG-W1	4/18/95 8:15	grab	4.06	1.83	0.094	0.057	6.0	7.68	8.18	12.08	60.0
M.F. Yuba R. below Colgate	SMP-YRMF-COL-W1	4/18/95 10:30	grab	2.06	1.15	0.026	0.015	3.0	7.70	7.41	12.44	62.0
Bridgeport	SMP-YRSF-BPT-W1	5/30/95 14:45	grab	5.44	1.39	0.050	0.029	20.0	7.17	13.40	12.00	32.0
Englebright	SMP-YUBR-ENG-W1	5/30/95 9:15	grab	2.52	2.07	0.012	0.029	4.0		12.90	11.40	54.0
M.F. Yuba R. above Colgate	SMP-YRMF-COL-W2	5/30/95 12:35	grab	4.04	1.25	0.043	0.012	5.0	7.46	14.20	11.00	59.0
M.F. Yuba R. below Colgate	SMP-YRMF-COL-W1	5/30/95 11:50	grab	2.35	1.11	0.015	0.017	3.0	7.76	8.40	12.00	68.0
Bridgeport	SMP-YRSF-BPT-W1	7/13/95 15:45	grab	2.45	1.31	0.104	0.072	4.0	7.11	17.86	9.57	32.3
Englebright	SMP-YUBR-ENG-W1	7/13/95 9:30	grab	1.42	0.82	0.043	0.020	3.0	6.95	11.94	11.80	44.3
M.F. Yuba R. below Colgate	SMP-YRMF-COL-W1	7/13/95 12:20	grab	1.30	0.91	0.017	0.013	3.0	7.05	8.27	12.37	53.7
Bridgeport	SMP-YRSF-BPT-W1	8/22/95 14:00	grab	2.01	1.60	0.058	0.044	3.0	7.40	23.50	7.14	105.9
Englebright	SMP-YUBR-ENG-W1	8/22/95 9:00	grab	1.84	1.11	0.040	0.015	3.0	8.23	11.00	11.20	57.5
M.F. Yuba R. below Colgate	SMP-YRMF-COL-W1	8/22/95 11:55	grab	1.76	1.22	0.010	0.014	3.0	8.06	8.50	12.30	54.1
Bridgeport	SMP-YRSF-BPT-W1	10/2/95 14:20	grab	1.77	0.74			3.0	8.05	18.06	9.91	121.3
Bridgeport	SMP-YRSF-BPT-W1	10/18/95 13:20	grab	1.06	0.62	0.052	0.042	3.0	7.67	15.48	9.28	128.7
Englebright	SMP-YUBR-ENG-W1	10/2/95 9:25	grab	1.57	0.77			3.0	7.33	12.37	11.20	66.0
Englebright	SMP-YUBR-ENG-W1	10/18/95 9:20	grab	0.92	0.33	0.039	0.044	3.0	6.57	11.24	10.45	63.6
M.F. Yuba R. below Colgate	SMP-YRMF-COL-W1	10/2/95 12:00	grab	4.70	1.09			3.0	7.45	8.71	12.40	55.8
M.F. Yuba R. below Colgate	SMP-YRMF-COL-W1	10/18/95 11:20	grab	0.68	0.65	0.034	0.031	3.0	7.12	8.85	11.34	57.4
Bridgeport	SMP-YRSF-BPT-W1	12/13/95 14:15	grab	54.87	6.15	0.189	0.075	110.0	7.13	10.19	10.47	42.9
Englebright	SMP-YUBR-ENG-W1	12/13/95 10:00	grab	1.27	0.78	0.043	0.018		7.05	9.85	10.54	61.7
M.F. Yuba R. below Colgate	SMP-YRMF-COL-W1	12/13/95 12:20	grab	1.86	0.73	0.043	0.019	3.0	6.94	8.91	10.89	51.0
Bridgeport	SMP-YRSF-BPT-W1	12/13/95 15:15	grab	38.45	6.28			57.0	7.15	10.23	10.45	43.6
Bridgeport	SMP-YRSF-BPT-W1	1/24/96 13:45	grab	74.86	8.19			90.0	7.53	6.80	12.74	58.1
Englebright	SMP-YUBR-ENG-W1	1/24/96 8:45	grab	8.48	2.83			5.0	7.28	8.82	11.86	61.7
M.F. Yuba R. below Colgate	SMP-YRMF-COL-W1	1/24/96 11:30	grab	21.61	6.03			36.0	7.58	7.11	11.26	59.6
Bridgeport	SMP-YRSF-BPT-W1	1/31/96 7:10	grab	7.29	6.64			7.0	7.54	8.54	12.07	67.6
Englebright	SMP-YUBR-ENG-W1	1/31/96 8:35	grab	8.68	7.01			7.0	7.37	8.47	12.39	58.7
M.F. Yuba R. below Colgate	SMP-YRMF-COL-W1	1/31/96 10:50	grab	2.07	1.08			4.0	6.81	8.70	11.86	61.7